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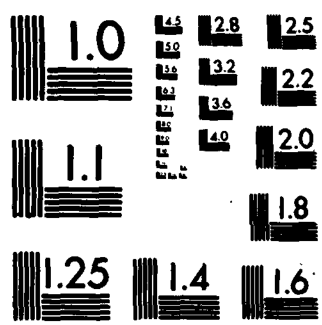

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THESIS

A PARAMETRIC ANALYSIS OF THE TECHNIQUES USED FOR THE RECOVERY AND EVACUATION OF BATTLE DAMAGED TRACKED VEHICLES

by

John Frederick Affeldt

June 1980

Thesis Advisor: S. H. Parry

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A PARAMETRIC ANALYSIS OF THE TECHNIQUES USED FOR THE RECOVERY AND EVACUATION OF BATTLE DAMAGED TRACKED VEHICLES

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Submitted in partial fulfillment of the
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I. INTRODUCTION

In today's combat analysis community there exists a plethora of outstanding combat models. Unfortunately, few of these models deal in any great detail with the logistics activities which form an integral, though often overlooked, part of the combat process. Many logistics activities, which can be termed combat subfunctions, are easily modelled. Indeed, such models as MAWLOGS, LOGATAK and MASC [4] are premier examples of relatively high resolution logistics models. But, just as the combat models either exclude logistics support altogether or include it in such a simplified format as to obviate any insight, so too, the logistics models tend to use rather weak combat models and therefore produce results which are not as useable as they could be.

This thesis presents a parametic model which allows the investigation of the recovery and evacuation of combat damaged tracked vehicles fighting in a defensive environment. The parametric analysis of recovery and evacuation techniques model (PARET) is a user interactive, TI-59 programmable calculator model which provides the following outputs:

a) red and blue force combat losses

b) time available for recovery

c) expected percentage of the blue losses which will be recovered

d) expected time to perform the recovery

e) expected number of recovery vehicles lost to enemy action

f) expected distribution of vehicles recovered by maintenance echelon required to return them to the user

g) expected time of combat vehicle return to the user

h) actual clock (elapsed) time

i) expected number of heavy equipment transporters required for a combat brigade.

PARET uses a hybridized, Lanchester based routine which produces both battle casualties and the time of battle for each engagement. In this manner, any red and blue force levels may be used to determine the overall impact on the recovery and evacuation processes. Battle time is determined in a purely deterministic manner; that is, it is dependent solely on the initial red and blue force levels and the user supplied red break point. The blue casualty level for each engagement is determined by the size of the starting blue force and the battle time computation. Since the blue force's combat effectiveness will decrease over time due to attrition by the red force, this model employs a variable exchange ratio instead of the more traditional attrition rates usually found in a Lanchestrian formulation.

Since the series of engagements being modelled is expected to last for several days, PARET keeps track of elapsed time in addition to the time for each engagement. Night and day

operations are played by the model by changing several parameters when the program determines night has fallen, and changes them back to their original values when sufficient time has elapsed for it to be daytime again. Additionally, the model includes the "fix forward" concept of maintenance operations, which means that some percentage of combat damaged vehicles can be fixed during the engagement period, and therefore will not need recovery or evacuation assets.

Functionally, PARET is arranged in four basic modules which perform the following tasks:

Module A: Module A determines battle time, red and blue casualties, the time available for recovery of the blue casualties and the expected number of recovery vehicles lost to hostile fire. In addition, this module determines the expected percentage of recoveries made using the daisy chaining technique of recovery, and when not using it. It allows the user to decide which recovery tactic to use. Once the recovery tactic is decided upon, the expected time to recover the casualties is displayed.

Module B: This module is a statistics generating and gathering program which uses the output from module A to determine the expected number of vehicles recovered based on the time available for recovery, computes the expected number of M, F and K kills which will be going to organizational and direct support maintenance (by type vehicle), and after computing elapsed time, resets certain parameters

depending on whether the conditions to be played are night or day conditions. Output from module B is then stored in the data base for use by the subsequent modules.

Module C: Module C uses the maintenance distribution generated in module B to compute expected times of return to the using unit for each combat vehicle. In addition, this module determines the distribution of maintenance for the recovery vehicles lost in combat, and computes the expected number of recovery vehicles which will be available to begin the next engagement (based on operational readiness rates).

Module D: Based on total numbers actually recovered, this module computes the expected number of heavy equipment transporters which will be required to carry the combat damaged vehicles to both direct support and general support maintenance units. It then computes the expected time of return of these equipment transporters to the maintenance collection point.

Chapter IV gives a detailed discussion of the construction of each module including the specific assumptions used. Several test cases using the model were run, and these cases along with detailed output are presented in Chaper V. Chapter VI presents the decision process used in determining recovery tactics, which vehicles to recover, and the mix of recovery vehicles to use, based on the parameters of the model. The general scenario used, a logistics primer and the model methodology are presented in Chapter II and III.

The PARET model exhibits many of the strengths and weaknesses of both the combat and logistics models now in use; however, its primary strength lies in the substantial flexibility gained by developing a model for the parametric analysis of one of the combat subfunctions through the hand-held programmable calculator.

II. BACKGROUND

A. PROBLEM STATEMENT

This thesis deals with a two-fold problem. First, it deals with the development of a logical, parametric approach to the analysis of the recovery and subsequent evacuation of combat vehicles for a force in a defense posture on a high intensity, conventional battlefield. Secondly, and as a logical next step, the decision process used in these two processes is analyzed.

To address both of these problems, a parametric model was built which uses the TI-59 programmable calculator as its vehicle. Although the calculator has many disadvantages for large scale analysis, its inherent power for the analysis of combat subfunctions has not yet been fully exploited. To the author's knowledge, PARET is the first medium scale logistics model with a realistic combat base which uses the hand-held calculator.

B. SCENARIO

Although recovery and evacuation operations in an offensive environment are not trivially easy, they are several powers of magnitude easier when compared to the same operations in a defensive environment. During delaying actions, combat damaged vehicles and those which become casualties through maintenance failure must be expeditiously recovered,

evacuated to the proper level of maintenance, and then returned to the user. A failure to recover puts an additional weapon into the hands of the continuously advancing enemy.

The PARET model uses a battlefield on which a series of pitched battles between armored forces is fought. Figure 2-1 displays this battlefield. In general, the situation is such that a blue force of brigade size is defending against a red force of division size. As Chapter V points out, in the cases which were run using the model, the red force was given unlimited resources; it attacked with all or part of a division against the remaining blue force in each engagement. PARET does not explicitly play terrain, but as Chapter IV points out, it can be modelled and played indirectly. All battles are considered to take place in the division main battle area. Chapter III discusses the exact force ratios considered.

When a delaying action is being played, one of the most critical parameters to be considered is the spacing of the red force echelons. Second only to spacing is the speed at which those echelons approach the blue force. The 5 km spacing shown in Figure 2-1 is the spacing employed in PARET. That parameter, however, can be easily changed in the model, as Chapter IV indicates. Second (and succeeding) echelon rates of advance are a user input parameter which can be changed at will in each iteration.

All of the forces normally found in units of the type specified in the figure are not played in the model. PARET

PARET BATTLEFIELD

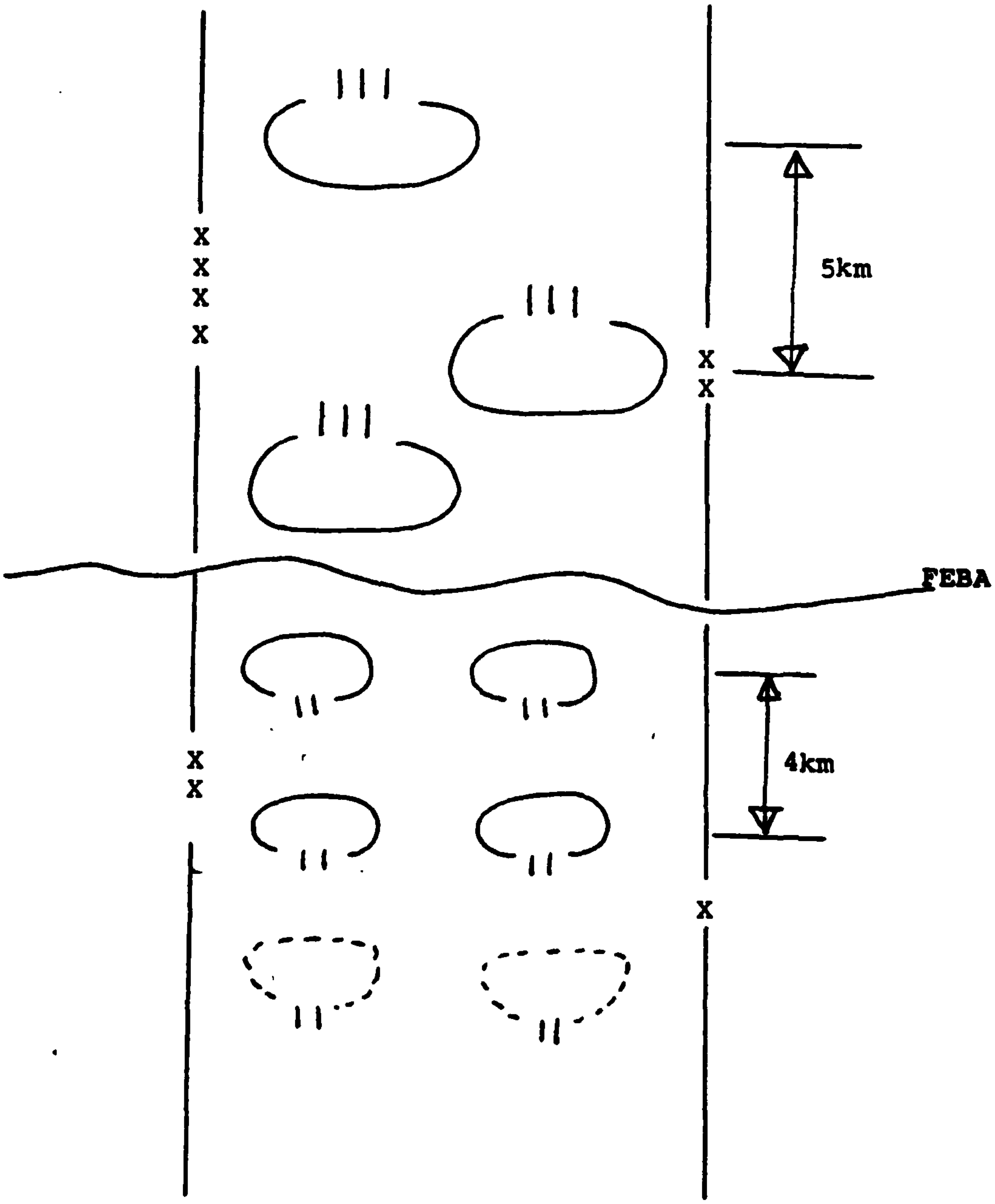

FIGURE 2-1

considers only the tracked weapon systems in both the red and blue forces. Specifically, the recovery and evacuation of only main battle tanks and TOW weapon systems is considered. Further, only those systems are used when considering the size of the blue force. Similarly, to compute the size of the red force, only main battle tanks and anti-tank weapons (SAGGER,BMP) are considered. Although the scope of this analysis is intentionally limited, tracked combat vehicles will be the bulk of the effort in terms of the recovery and evacuation effort.

It is important to note that although Figure 2-1 presents an idealized battlefield, the model is not necessarily tied to any particular fixed situation. That is, the spacing between blue alternate battle positions, the red echelon spacing, and the size of the opposing forces are all user inputs to the model through direct interaction or through directly changing an appropriate line of code in the program itself. Further details impacting on the specifics of the particular scenario played are explained in Chapter III.

C. LOGISTICS PRIMER

The lexicon of combat and combat analysis is relatively well known. Most analysts (and many commanders), however, feel uncomfortable when they must deal with the mysterious world of logistics. As an aid to the reader, the following listing of terms common to the areas of logistical support this thesis deals with should prove helpful.

Recovery: the process of removing combat damaged, mired, or otherwise immobile vehicle from the battlefield. During combat, a vehicle is recovered to a maintenance collection point. Recovery is the first, and often most difficult, stage in the cycle which eventually will return that vehicle to the user.

Evacuation: the process of moving inoperable equipment from the maintenance collection point to the appropriate maintenance activity. Evacuation of tracked vehicles is normally accomplished by heavy equipment transporters, capable of travelling at relatively high rates of speed over good roads.

Heavy Equipment Transporter: a tractor-trailer combination used to move disabled tracked vehicles from the maintenance collection point to the appropriate level of maintenance. In common parlance, the heavy equipment transporter is the HET. Currently, the HET is a combination of either a 22 1/2 ton, 15 ton, or 10 ton tractor with an M747 trailer. The HET is capable of carrying a main battle tank over good roads at speeds up to 40 MPH.

Maintenance Collection Point: the area to which disabled vehicles are recovered and subsequently evacuated from. The MCP is generally located 10 to 15 km behind the forward edge of the battle area (FEBA). Elements of the direct support maintenance company, along with organizational maintenance personnel, are located at the MCP and provide on-site

repairs and inspection. If repairs cannot be performed here, the disabled vehicle is evacuated to the direct support company further in the rear where appropriate disposition will be made.

Level of Maintenance: there are four levels of maintenance in the US Army maintenance system:

a) organizational: capable of minor repairs such as one might find at a civilian service station. Each company and batallion has organic organizational maintenance personnel.

b) direct support: capable of more extensive repairs than the organizational level, but limited to such tasks as engine replacement. In general, the direct support (DS) maintenance level replaces defective major components of all vehicular systems including armament and fire control. Each combat brigade has a DS maintenance company attached to it. Usually, this company is located as near the FEBA as is practical to afford support. Additionally, the divisional direct support batallion has a DS company (rear) which is located 35 to 50 km behind the FEBA. This rear DS company provides additional backup to each forward company.

c) general support: capable of the highest level of field repair. The GS company provides support in those areas which the DS company lacks capability, provides backup DS capability for overflow, and provides rebuild of those major components which the DS company exchanges. The GS company is usually located 100 km from the FEBA to avoid frequent displacements due to the enemy's advance.

d) depot: capable of repair up to total overhaul of entire systems. Depot maintenance is comparable to sending the vehicle back to the manufacturer for repairs. Usually, the depot facility will be located in CONUS, or so far to the rear that evacuation to this level generally requires issuances of a replacement vehicle to the using unit.

Recovery Vehicle: one of three types of vehicles used to haul a disabled vehicle from the battle site to the MCP. The following recovery vehicles are now in the inventory:

a) M88: a full tracked, medium armored vehicle capable of recovering the main battle tank.

b) M578: a full tracked, lightly armored vehicle capable of recovering self propelled artillery, the Infantry Fighting Vehicle (IFV), the Improved TOW Vehicle (ITV), or any vehicle in the armored personnel carrier class.

c) M553: a wheeled, 10 ton wrecker designed for recovery of wheeled vehicles, but capable of recovering the IFV/ITV class of vehicles under favorable conditions.

Daisy Chaining: the process of recovering more than one disabled vehicle with only one recovery vehicle. The tracked recovery vehicles are capable of recovering several other vehicles simultaneously, but the time to rig the vehicles for towing and the towing speed change markedly.

Self/Like Recovery: a recovery effected by a vehicle of the same type, or recovery performed by the vehicle itself. In many cases, it is expeditious to perform recovery through

this method, both to conserve recovery assets for more demanding missions, and to save valuable time which would otherwise be wasted in waiting for the recovery vehicles to arrive at the site of failure. For example, a tank which has suffered only a firepower kill would be able to recover itself, and could be used for the recovery of other, more seriously damaged, vehicles.

The limitations and capabilities of the various recovery vehicles above can be found in the Battlefield Recovery and Evacuation Capabilties Study [3]. Other logistics terms used in this thesis will be explained as they are presented.

In war, many of the problems which the logistician will face will require unique solutions not dreamt of even ten years ago. The methods of combat are dynamic, and so too must be the methods of supporting the fighters. A defensive environment will require the logistics system to support an Army in the field with little backup for an extended period of time, a time critical to our ultimate survival. The PARET model provides yet another tool for the analysis of one of the primary combat subfunctions, the recovery and evacuation of damaged fighting vehicles.

III. METHODOLOGY

A. MODEL COMPLEXITY

During the last ten years, the general trend in the combat analysis community has been to devise highly complex computer models capable of providing detailed output to answer an unlimited number of detailed questions. These high resolution models, such as STAR (a Simulation of Tactical Alternative Responses) which was developed at the Naval Postgraduate School, allow the total analysis of nearly any conceivable tactic or weapon system. Through technical evolution in the state of the modelling art, high resolution models have established a permanent niche for themselves in the decision maker's arena.

The dynamic nature of combat has spawned the demand for ever increasing complexity in the models used by analysts. Unfortunately, the complex model creates complex demands for extensive data input, ponderous amounts of annual maintenance man hours, and a great deal of time for the analysis of the output data. Cumbersome as they are, the high resolution models are valuable tools which are necessary in most modelling applications in the defense industry. Often, the computer simulation is the only source of answers posed by senior commanders; still more often, those same simulations pose questions not yet dreamed of by commanders or analysts.

While recognizing the intrinsic need for models such as STAR, it is the purpose of this thesis to present an alternative approach to the increasing complexity running rampant in the modelling community. Many of the combat subfunctions in the area of logistics are easily modelled in a parametric form. Too often, a logistics function is put into a high resolution combat model before that function is thoroughly understood. This lack of understanding of the parameters which enter the overall equation cause improper conclusions to be drawn regarding the nature of the logistics function under study. Since all of the functions in combat are interrelated, a basic misunderstanding of any one will generate a less than adequate understanding of the total process.

The intent of PARET is to present the analytical community with a quick, inexpensive and highly useable tool for the in-depth investigation of the parameters influencing how and why tracked vehicles are recovered from the battlefield, evacuated to the appropriate level of maintenance, and then returned to the using unit. Technical evolution in the computer industry has brought added innovation in the field of hand-held programming as well. PARET will not provide the voluminous, detailed output characteristic of the computer simulation; it will provide the analyst a means of conducting exhaustive sensitivity analyses on the parameters surrounding battlefield recovery and evacuation in a timely and very inexpensive manner. As Chapter V points out, the data collected

from the test cases run on the model compare very favorably with data generated in large scale simulations, and in some cases, provide new insights into the processes under study.

B. ASSUMPTIONS

In order to focus on the particular areas to be studied, the following general assumptions were made for ease of modelling:

a) fuel and ammunition resupply are not considered

b) no recovery missions are refused

c) recovery crews are always available for every recovery vehicle

d) the model is independent of the type of control (centralized or decentralized) exercised over the recovery vehicles

e) terrain is not directly of interest

The description of each module, in Chapter IV, includes the specific assumptions used in the construction of that particular module.

C. PARAMETERS ANALYZED

As Chapter II pointed out, the PARET battlefield is designated to include one brigade's area of operations. The hypothetical blue brigade consists of two mechanized infantry batallions and two armored battalions. A combination of one batallion of each type forms a battalion combat team which occupies adjoining battle positions on the battlefield.

Only tanks and anti-tank weapons are considered when the size of the force is computed. Throughout the remainder of this thesis, the word TOW is taken to mean the family of the vehicular mounted weapon systems which include the TOW missile. Each blue force battalion team consists of the following weapons mix: 54 tanks, 88 TOW's (142 total systems). Similarly, the opposing red division is composed of only two primary weapon systems, tanks and anti-tank weapons. For the purpose of this model, the red force division is composed of two mechanized rifle regiments and one armor regiment. One red force regimental team is composed of 57 tanks and 119 anti-tank weapons (176 total weapon systems). Although this force ratio appears to be less than 3:1, recall that these red regimental teams will appear on the battlefield incessantly, opposing a steadily dwindling blue force.

The primary attribute of the red force for the purposes of this model is its belief in the principle of momentum. That is, the red force will advance with the maximum mass it can muster at the highest attainable speed. At the beginning of each iteration, the size of both the blue and red forces are entered by the user. Additionally, the user inputs the rate of advance of the succeeding red echelon. The red force rate of advance turns out to be one of the most critical parameters for successful recovery operations in the defensive environment. PARET does not play any other weapon systems than those already mentioned, insofar as model

components. However, artillery fire is played indirectly in the model. Blue indirect fire is allowed to slow the red rate of advance for each of the succeeding echelons, and red indirect fire is considered in the attrition of the blue recovery vehicles. Successful interdiction of the red rate of advance is as important to recovery and evacuation operations as the operational readiness of the blue recovery vehicles.

It is conceivable that the red force divisions would be separated by as much as 20 km during the movement to contact. To model the maximum strain on the blue recovery system, this spacing was not played in PARET. If these spacings had been played, the series of engagements described in Chapter V would have turned out considerably different since that additional time would allow more blue replacements to re-enter the battle. Chapter IV discusses how this additional time factor can be modelled, and Chapter V displays some data which has been modified to incorporate the added time.

Blue and red force maneuvers were not considered in the formation of the model. Undoubtedly, maneuvering will take place during the time of battle at the red and blue company/battalion level. However, when the entire red force is considered, its movement generally in a straight line through the blue area is a reasonable assumption to make. Similarly, the blue force will employ some type of maneuver when it breaks contact and moves to the next battle position. Again the movement to the alternate battle position is assumed to

to be in a straight line. No extra time was considered for the blue passage of lines.

D. TACTICS CONSIDERED

Blue Force: Two tactics were considered for the defending force. First, the blue force was divided into two battalion teams as described above. Each team occupied a battle position, and these positions were set at a distance of 4 km from each other. When the red force reached its pre-set breakpoint, the blue force then withdrew to its next battle position (already prepared), 8 km from the first. The advancing red force, then, would meet fresh blue forces in the first two battles, and the same blue force during alternate battles after the second. Upon reaching the point where only 50% of the blue battalion team was still alive, the battalion teams would consolidate forces on the next battle position, continuing to fight in the manner just described until the remaining force reached the 50% level. At that point (71 blue weapon systems alive) the problem was terminated.

The second tactic considered for the blue force involved setting up the battle field identically to that above. However, in this case, the original blue battalion team stood and fought on the first battle position until it reached the 50% level. It then broke contact and moved to the position of the second battalion team, combined forces, and waited for the next battle. Battle termination came when the blue force had 71 systems left alive on the battlefield.

Red Forces: Each red force regimental team fought until it reached its pre-set breakpoint (in the permanent data base). When the breakpoint was reached, the red force went into the hasty defensive posture while it waited for the next echelon to catch up to it. Time was allotted for the rollup of the red force and an expected time for it to begin to move forward again was computed. For the cases examined in Chapter V, the red force went into hasty defense when it reached the 40% survivor level.

These tactics are not representative of all the tactical decisions available to the commander. They did, however, provide a suitable framework in which to study the recovery and evacuation processes. The 40% survivor breakpoint for the red force made each battle a little longer than the one which preceeded it since the blue force was continually being attrited by the red force. Blue attrition of the red force meant little in the practical sense since the red force was allowed to be virtually limitless. PARET assumes continuous combat in the sense that the only idle time for a blue element is the time in which it is travelling to its next position, and the time it takes the red column to again make contact. In combination, these factors allowed the analysis of the recovery and evacuation processes under worst case conditions.

E. OUTPUT ANALYSIS

Chapter V presents all cases considered in the trial runs of the PARET model. To gather the data used in the analysis, a worksheet was constructed which allowed the transcription of the data as it came from the calculator. One of the most significant disadvantages of using the hand-held calculator for an analysis of this sort is that of data collection. As Chapter IV will point out, it is possible to collect some of the data internally in the model, but a large portion of it must be collected iteratively as the model is running. Enough additional room has been allocated to each card of the program to allow data collection routines to be added, but this was not done for this study in order that all of the elements of the process could be studied in greater detail.

For example, module D predicts how many HET's will be required for the brigade. But the prediction process begins at each battle termination in a sequence of battles. That is, the user must manually tally how many HET's he has; if the prediction is less than the number now on hand, no additional HET's are required. A routine to output only the additional HET requirement is easy to add to this module, and would make data collection simpler, but less enlightening.

IV. MODEL DESCRIPTION

In this chapter, the PARET model is discussed in detail. Appendix A is the complete user's manual for the model, including a program listing which conforms to the descriptions presented in each module. The design of the PARET model was carefully considered to allow easy conversion for other models of calculators, or for conversion to either FORTRAN IV or SIMSCRIPT. Before any conversion is attempted, however, it is imperative that the reader carefully digest the description of each module. Modelling assumptions are included in the discussion of each module, and the key to the successful use of this model lies in the complete understanding of the assumptions used, and how they may be changed through appropriate data entry.

The modular design of PARET allows each module to be used as a separate, complete model in its own right. When PARET is run in its entirety, the data base is updated for the use of the succeeding module. Therefore, if modules are to be used alone, care must be taken to insert proper parameters in the data base. Annex C of Appendix A lists the complete data base used in this presentation. Annex C is of particular use since nearly all specific assumptions to be described are directly related to values in the data base. Parametric changes in the data base will allow the user to tailor PARET for the analysis of particular situations.

Note that only those data locations listed as permanent will remain unchanged throughout the entire model. For the other data locations, a cascading technique was employed which means that data generated by a module and stored in a data location will only remain unchanged through that module. If further access to that particular data is required, the data base and the coding of the module itself will have to be altered. Also due to the cascaded data base, it is imperative that the modules of PARET are run in sequence. Otherwise, data required for a particular module's execution will not be in place in the data base, and erroneous output will be generated.

Chapter I outlined the primary functions of each of the four modules in the PARET model. The modules compute other data than that listed in the brief description already given. In the discussion to follow, all of the functions of each module are listed; the numbered entries describe the assumptions used in the development of each piece of the module.

A. MODULE A

This module performs the following functions:

a) computes the battle time for each battle based on the initial red and blue starting forces and the red force break point.

b) computes a stochastic interdicted rate of advance for the red force.

c) computes recovery vehicle travel time to the battle site and to the MCP.

d) computes the time available for recovery of battle damaged vehicles.

e) computes the number of disabled vehicles which must be recovered by recovery vehicles (vice those which are self/like recoverable).

f) computes red and blue survivors and battle termination.

g) computes the expected time to perform the recovery assuming no attrition of recovery vehicles.

h) computes expected percentage of recovery without daisy chaining.

i) computes expected percentage of recovery with daisy chaining.

j) allows user selection of which recovery tactic to use.

k) computes the expected number of recovery vehicles killed during movement to the battle site, on the battle site, and during movement to the MCP.

1. Battle Time

Battle time, as used for the purposes of this model, is that time in which the red and blue forces are in contact. Red and blue force size, the postulated exchange ratio, and the red break point all play important roles in the determination of the length of a particular battle. To achieve computational speed, a Lanchester type equation for determining the battle time seemed appropriate. Since the blue force

was postulated to be diminishing in relation to the red force which was nearly constant for each battle, it was necessary to modify the basic Lanchester fixed break point battle time equations [2] to allow for an exchange ratio which was implicitly time dependent. Further, by assuming the force makeup of Chapter III, it is possible to use homogeneous Lanchester equations, since all weapon systems can be thought of as "tank killers."

In the classical Lanchester approach, attrition rates are postulated for each force, and these attrition rates are held constant for any particular analysis. But, as the size of the blue force diminishes in relation to the red force, the intrinsic combat effectiveness of the blue force also diminishes with time. To allow for this contingency, PARET uses an exchange ratio which is solely dependent on the size of the blue force which begins any particular battle. By using the initial force ratios (176 red, 142 blue) and assuming that the defender has an initial exchange ratio of 5:1 (i.e. one defender is killed for every five attackers), the exchange ratio can be defined by:

$$X=EXP(-(L)(BO)) \qquad (4\text{-}1)$$

where L is a constant defined by taking X = 5 when BO = 142. BO in this case is the size of the blue force at the beginning of any particular battle. The exponential form of exchange ratio was used to give the blue forces less and less combat

effectiveness as its size decreases through attrition. When the blue force hits the 50% level of survivors, the value of X is nearly 1, meaning that the blue force loses one weapon system for each red system that it kills. Note that the assumption is being made that combat effectiveness and exchange ratios are roughly equivalent. If other than an initial 5:1 exchange ratio is desired, recompute the value of L and put it into the permanent data base (see Appendix A, Annex C).

The actual computation of battle time involves the use of two equations. Equation 4-2 is used whenever the initial force ratio (red/blue) is not equal to the square root of the exchange ratio [2]. When the preceeding condition is not met, equation 4-3 is automatically selected to determine battle time.

$$TB = X^{-\frac{1}{2}}\ln[(-Y(BP)+((1/X)-Y^2(1-BP^2))^{\frac{1}{2}})/X^{-\frac{1}{2}} - Y))] \quad (4\text{-}2)$$

$$TB = -X^{-\frac{1}{2}}\ln(1-BP) \quad (4\text{-}3)$$

In these equations, Y is the force ratio (red/blue), and BP is the pre-set red force break point. BP is a value in the permanent data base, and for the cases studied in Chapter V, was taken to be 40% (i.e. the red force fought until it reached the 40% survivor level). X is the exchange ratio defined by 4-1. Note that these equations are the same as those defined in [1] for the homogeneous, fixed breakpoint model, with the exception of the substitution of the exchange ratio for the normally fixed attrition coefficients.

2. Interdicted Rate of Advance

The rate of advance for the succeeding and second echelons of the red force are input by the user for each battle in a sequence. Interdiction (slowing) of this advance rate is accomplished during each battle iteration through two factors in the permanent data base which control the level of interdiction. The amount of time available for recovery operations is directly proportional to the speed at which the next echelon can close with, rollup and begin attacking with, the echelon in contact. Therefore, the level of interdiction which the blue force can deliver is directly related to the overall recovery time available. For all cases discussed in Chapter V, the level of interdiction was allowed to vary stochastically between 0 and 50%. The interdiction factors in the data base are used as the endpoints of a uniform distribution, and the interdicted rate of advance is computed according to the relation:

$$RI = R/I \tag{4-4}$$

where R is the initial rate of advance (user input), I is the interdiction factor and RI is the interdicted rate of advance. To play no interdiction, it is only necessary to put a 1 into each of the permanent data base locations listed in Annex C of Appendix A.

Note that RI is inserted into the permanent data base and is used whenever the red advance rate is required in

subsequent computations. A new interdicted rate of advance is not computed until module A is exercised again.

3. Travel Time to the Battle Site and MCP

Based on the user supplied cross country speed for recovery vehicles, travel times are computed based on the distances to the battle site and the MCP which are input at this stage of the program. Since cross country speed is in the permanent data base, this figure can be manipulated to play differing terrain. No red interdiction of recovery vehicle speed is assumed for this model. The travel time of the recovery vehicles is an integral part of the equation for the time available for recovery. In the cases discussed in Chapter V, various cross country speeds were used to test the overall impact of this parameter on the recovery operation. The computation performed in this step is simply distance/speed, where both are expressed in the same units of measurement. Although only one cross country speed is designed into the model, the small variations in capability among the various recovery vehicles to cross country speed will have little overall impact on the outcome, and so was not played.

4. Time Available for Recovery

For the purposes of this model, the time available for recovery is called the critical time (TC). The travel times computed above as well as the RI value enter into the computation of TC. PARET does not assume perfect information flow between the forces in contact and the recovery

crews. That is, the locations of disabled vehicles will not be known with perfect certainty, and it is possible for the recovery crews to get lost enroute to the battle site or the MCP, especially at night. To allow for this contingency, the permanent data base includes a disorientation factor (D) which is entered as a percentage. If the value of D is anything other than 0, that percentage of the total travel time will be added to the computed travel time. D is automatically increased when the transition to night operations is made. Another use of the D factor might be to play smoke on the battlefield, which would hinder recovery operations to some degree.

Also in the permanent data base is a mean hook up time, that is the mean time it should take a recovery vehicle to rig a disabled vehicle for movement, barring any complications. This time was extracted from field trials discussed in Ref. 3, and was held constant for the cases examined in Chapter V. The mean hookup time is used as the mean of a normal distribution of hookup times in the model. Both the mean hookup time and the standard deviation for the distribution of all hookup times are easily changed.

It was assumed that the red echelon in contact moves at 1 kmh. Further, the assumption was made that all battles take place at a distance of 1 km. To change either of these parameters, a multiplicative factor must be introduced into the model coding. As shown in Figure 2-1, the spacing between echelons

of the red force were assumed to be 5 km. Echelon spacing is a single line code entry in this subroutine (Annex B, Appendix A).

Based on the foregoing distance and speed assumptions, the next parameter to be considered is the time it takes for the next echelon to rollup the echelon in contact and restart the advance. During battle time, the lead element (the echelon in contact) will move a distance equal to the time of battle (or nTB if some speed other than 1 kmh during contact is assumed). The follow-on echelon will close with the echelon in contact at RI. When these two echelons finally join, there will be a finite period of time during which the units combine forces and begin to advance again. Stored in the permanent data base are two parameters which form the end points of a uniform distribution representing this rollup and restart time (TRR). The cases of Chapter V used TRR bounds of 5 and 10 minutes. Combining all of these factors produces:

$$TRR = (spacing/RI) + TB + U(a,b) \qquad (4\text{-}5)$$

where TB is the battle time computed above and U(a,b) represents the uniformly distributed random variable with a = 5 and b = 10 for this case. Note that to make a different assumption about the speed of the echelon in contact, it is only necessary to insert the proper multiplicative factor ahead of TB in 4-5.

Simply stated, the time available for recovery (critical time) could be expressed as TB + TRR. However, this formulation assumes that the recovery crews are notified as soon as the first blue vehicle is disabled, and that the first blue casualty occurs immediately at the start of TB. PARET does not make those assumptions. The first blue casualty occurs sometime between time 0 and the time it takes to kill up to the value of the exchange ratio (X) of red systems. For this model, the assumption is made that the blue forces surprise the red forces (i.e. the first casualty is red). Further, it is assumed that there will be X red casualties (the value of the exchange ratio) before the first blue casualty occurs. This assumption is made to provide the largest correction factor for TC, thereby providing another worst case situation. If it is assumed that the red casualties occur uniformly over TB, then the following relation provides the necessary correction for TC:

$$C = -X(TB/\text{red losses}) \qquad (4\text{-}6)$$

where X is the exchange ratio and TB is the battle time. Note that the uniform loss of red systems is a key consideration in this correction factor. The factor, C, will be in the same units as TB (hours in this model). With this correction factor, the time available for recovery can be stated as:

$$TC = TB + TRR + C \qquad (4\text{-}7)$$

where TC is critical time, TRR is the time to rollup and restart, and TB is the battle time.

5. Number of Vehicles to be Recovered

In computing candidates for recovery, PARET does not take into account random breakdowns or vehicles which have become mired on the battlefield. There will be numerous maintenance failures as the length of the sequence of battles increases, and weather conditions over a several day span could surely cause many mired combat vehicles requiring recovery. By decreasing the number of unrecoverable candidates and by decreasing the amount of self/like recovery allowed, both of these categories can be played in the model.

From the outset in the design of the model, the assumption was made that there will be some percentage of the blue casualties which will be unrecoverable, or not feasible to recover due to the extent of the damage they received. The permanent data base contains a factor for this number of unrecoverables, expressed as a percentage of the total number of candidates. For the test cases run, this percentage was taken to be 10%.

Current recovery doctrine [3] specifies that the owning unit has primary responsibilities for the recovery of its own assets. The number of vehicles which can recover themselves, and those which are capable of being recovered by a like vehicle, substantially reduce the recovery requirement for the recovery vehicles. In the permanent data base is the

self/like recovery factor, which is expressed as a percentage of the total number of casualties. The test cases in Chapter V explore several levels of the self/like recovery percentage.

The relation for the number of vehicles which must be recovered by the recovery vehicles is then:

$$NR = \text{casualties} - \text{self/like } \% - \text{unrecoverable } \% \quad (4\text{-}8)$$

6. Red and Blue Force Survivors

Red and blue force survivors are computed through a simple application of the red break point and the exchange ratio. Red survivors are given by:

$$RT = BP(RO) \quad (4\text{-}9)$$

where RT are the red survivors at time T, BP is the red break point, and RO is the size of the initial red force. Using this value, the blue survivors are:

$$BT = BO - (RO - RT)/X \quad (4\text{-}10)$$

where BT is blue survivors at the time T, BO is the starting blue force, RO is the starting red force, and X is the exchange ratio.

7. Expected Time to Recover the Casualties

The decision on which recovery technique to use is based in part on the comparison of the expected time required for recovery with the critical time. For example, if the critical time (TC) is less than the time expected for recovery

of all the casualties, some tradeoffs must be made by the commander. Chapter VI discusses the decision factors used in PARET in great detail.

The only user input parameter for this computation is the number of recovery vehicles available to send on the mission. Therefore, immediate sensitivity analysis of this parameter is possible; this portion of the program could be used, for example, to determine the expected number of recovery vehicles required to recover the entire force within the TC parameter's range. In this computation, it is assumed that no recovery vehicles are lost.

If it is assumed that all recovery vehicles arrive at the disabled vehicles they are able to recover simultaneously, then it can be assumed that the hookup time computed earlier is the hookup time for all of the vehicles to be recovered. This last assumption is not strictly valid since the greatest hookup time for the entire group is the constraining variable; however, the hookup time is a normally distributed random variable and over several battles in a given sequence, the difference between this method and generating hookup times for each vehicle to be recovered is beyond the resolution of the model. Using these assumptions, the expected time of recovery is given by:

$$TR = (2(NR/NA) - 1)(TTH + TH) + TT \qquad (4\text{-}11)$$

where TR is the expected time to recover the casualties, NR

is the number of disabled vehicles to be recovered, NA is the number of recovery vehicles available to perform the mission, TTH is the travel time from the recovery site to the MCP, TH is the normally distributed hookup time, and TT is the travel time from the recovery vehicle assembly area to the recovery site. The first term of 4-11 determines how many trips must be made by the recovery vehicles to recover all of the casualties. Note that this formulation does not assume daisy chaining will be used and does not assume any attrition of the recovery vehicles. At the MCP, the recovery vehicles will require a small amount of time to offload the disabled vehicles; however, this time is so small in comparison to the other times being considered that it was omitted from this formulation.

8. Expected Percentage of Recovery (no daisy chaining)

Current doctrine calls for daisy chaining whenever possible in order to maximize the number of vehicles recovered in a given amount of time. Intrinsic to the PARET model, however, is the assumption that the single most important parameter influencing the number of recovery vehicles lost on the battle site is the time it takes them to actually hookup and move away with a disabled vehicle in tow. Daisy chaining will increase this time substantially, and therefore makes the number of recovery vehicle losses much higher in this model. The section describing the computation for probability of kill on the recovery vehicles will describe the functional relationship of the time parameters involved. For now, it is

sufficient to note that daisy chaining is sometimes less than desirable in the PARET context. Assuming no recovery vehicle attrition, the expected percentage of recovery candidates recovered without daisy chaining is given by:

$$R = (TC/TR) \quad (4\text{-}12)$$

where R is the expected percentage recovered, TC is the critical time, and TR is the expected time of recovery.

9. <u>Expected Percentage Recovery (with daisy chaining)</u>

For this computation, equation 4-12 is again used with the following modifying assumptions. When daisy chaining is used, only two vehicles are allowed to be towed by one recovery vehicle, the time to hookup the two vehicles is exactly twice that for a single vehicle, and the travel time to the MCP is 1.5 times as great as that when no daisy chaining is used. To implmement these assumptions, TC is doubled, as is TH; TTH is multiplied by 1.5. Doubling the value of TC (critical time) has the same effect as being able to recover twice as many vehicles in the same amount of time. Doubling the number of recovery vehicles available would have the same effect as doubling TC.

At this point, the user has the two percentage of recovery figures. If daisy chaining is elected based on some decision rule (see Chapter VI), a keyboard entry is made and the changes mentioned above are made permanent for this iteration. Chapter V describes the effect of exercising this option.

10. Expected Number of Recovery Vehicles Killed

During the recovery process, the recovery vehicles are exposed to attrition three distinct times in the PARET model. While moving from the assembly area to the battle site, the assumption is made that the recovery vehicles will be exposed to indirect fire only; i.e. no direct fire attrition is allowed during this phase. On the battle site itself, the recovery vehicles are assumed to be exposed to direct fire attrition only. Then, during the movement to the MCP, only indirect fire attrition is assumed.

The underlying assumption in the following formulation for the probability of a hit (PH) on a recovery vehicle is that PH is functionally related to the time of exposure of the recovery vehicle to enemy fire. Further, the assumption is made that on the battle sit itself, PH is a function of time of exposure, and not of the proximity of the enemy firer's. Attrition modelling can be done using either the distance to enemy relationship or the time of exposure relationship; for passive targets such as recovery vehicles, the time relationship has more intuitive appeal.

For each of the movement phases in the attrition process, two alternative methods of determining a probability of hit were investigated. The first of these involved using a Lanchester equation of the form [2]:

$$L = EXP(-Qt) \qquad (4\text{-}13)$$

where L is the total number of losses, Q is (-a/A)(V)(PK)(xy), where a is the area presented by each recovery vehicle, A is the total target area in which the recovery vehicle moves, V is the red force rate of fire per hour, PK is the probability of a kill given a hit, x and y refer to the size of the blue and red forces respectively, and t is the time of exposure to enemy fire. If it is assumed that the recovery vehicles move in a rectangular area whose length is the distance to be travelled and whose width is, for example 200 m, this formulation produces a small number of casualties (less than 2 casualties from a force of 8 recovery vehicles). Even though this equation gives the number of losses during movement a direct functional relationship with the time of exposure to enemy fire, it kills recovery vehicles every time it is employed. Given that the recovery vehicles are being exposed to unobserved indirect fire during the movement phase, it is reasonable to expect that attrition will not take place during each movement. After trying many methods of expressing PK and rates of fire to give intuitively appealing loss figures using this model, another direction was taken which fulfills the assumption that losses do not necessarily have to occur during movement.

PARET uses a parametric computational form in determining the losses sustained during the movement phase. A basic assumption is made that if a hit occurs, there will necessarily be a kill; i.e. the probability of a kill given

a hit is 1. When vulnerability data on recovery vehicles becomes available, the model can be easily changed to compute actual probabilities of kill given hits. For a recovery vehicle, two kinds of kill are possible: mobility and catastrophic (m and k). These kills are further subdivided by the model into the level of maintenance required to effect repairs, thereby allowing an expected time of return of the recovery vehicle. The probability of kill on a recovery vehicle during movement is given by:

$$PK = (\tan(TE))^{\frac{1}{2}} \qquad (4\text{-}14)$$

where TE is the time of exposure for each recovery vehicle. TE will be TT (travel time to the battle site) or TTH (travel time to the MCP) depending on which leg of the movement the vehicle is on. There are many functional forms which could be used to provide a monotonically increasing value of PK as TE increases. The tangent function was chosen because it provides high values of PK when the time of exposure gets large (greater than 1 hour for example). Table 4-1 gives a listing of some exposure times and the associated PK using this relation. To determine if a kill is scored, a PK is computed for <u>each</u> recovery vehicle sent on a mission; a U(0,1) random number is drawn, and if the PK for that vehicle is greater than the random number, a kill is tallied and the number of recovery vehicles left alive is reduced appropriately. This routine is the longest running routine of the PARET model

since it computes a PK and a random number comparator for each vehicle alive for each of the three phases mentioned above. If 10 recovery vehicles are sent on a mission, several minutes of computation time will be required to determine the total number of kills.

TE(hours)	PK
.1	.04
.5	.09
1.0	.13
1.5	.16
2.0	.19

Table 4-1

The probability of kill on the battle site requires the consideration of more parameters than that for the movement phases. Even though the basic assumption of PK being independent from the distance to the enemy firers holds on the battle site, many of the traditional parametric ideas from the distance dependency formulation are useful here. In PARET, the assumption is made that the red force has some scheme of assigning target priorities, and that the red weapon system will tend to fire first at targets which present apparent danger to it, thereby assigning a lower priority to passive targets such as recovery vehicles. A target priority, then, can be thought of as having the effect of reducing the

effective time of exposure if the priority system in use favors the passive targets. For this formulation, "bigger is better," i.e. if a priority of 5 is assigned to a recovery vehicle, that is better than having a priority of 1 assigned to it. The cases considered in Chapter V use a target priority of 5 for the recovery vehicles. Priority is a value stored in the permanent data base.

The attacker also has a finite probability of correctly identifying a target once it is acquired. Such things as battlefield smoke, interdictory fires, or night operations all degrade the red force's ability to correctly identify an acquired target. For example, if the attacker identifies an acquired target as a tank (which has a target priority of 1 on his target list), but the target is in fact an M88 recovery vehicle, the probability that the M88 will be killed is greatly enhanced. In the context of exposure time, incorrect identification can be thought of as increasing the effective exposure time of the recovery vehicle. The probability that an attacker has line of sight on the targets before him also enters into the consideration of identification. Another factor which enters the formulation is blue supressive fire, which can be thought of as having the effect of reducing the effective time of exposure of recovery vehicles. For a recovery vehicle on the battle site, the basic unit of exposure is the hookup time. However, the assumptions just presented can be interpreted to mean that the "effective" exposure time, that is,

some percentage of the actual time on the battle site during which the recovery vehicle can be expected to be exposed to enemy fire, can be expressed by:

$$TE = L_S(1 - S)(Z)(P)(TH) \tag{4-15}$$

where L_S is the probability that line of sight to recovery vehicle exists, S is a random percentage of suppression from the blue force, Z is the reciprocal of the target priority, P is the probability of the red force incorrectly identifying a recovery vehicle after acquisition, and TH is the hookup time.

For example, if it is assumed that the acutal hookup time is .5 hours, the probability that line of sight exists is .5, and if the red force is experiencing 90% suppression, the priority of a recovery vehicle is 5, and the probability of a recovery vehicle being incorrectly identified is .7, then the value of TE would be .0035 hours.

The probability of a kill (PK) is assumed to be some function of this time of exposure. As in the case of the movement phase, it is desired to have some functional relationship which causes PK to rise sharply as the time of exposure increases. There are many functions which will fulfill these requirements, as was pointed out in the explanation of the PK during movement. PARET uses the following functional form because of the smooth rise of PK with time and its intuitively appealing results:

$$PK = ABS(1/\ln TE) \qquad (4\text{-}16)$$

where the absolute value is taken to yield a montonically increasing function. To determine if a kill is scored, a random comparator is drawn as was done for the movement phase. The appropriate number of kills is tallied, and the number of recovery vehicles left alive are used for the movement phase from the battle site to the MCP.

All of the parameters listed above are in the permanent data base for flexibility in defining the conditions of a particular battle. For example, an increase in the probability of line of sight could be used to play more open terrain, while a decrease in the probability of incorrect identification might be used to mean less reliance on infrared detection devices by the red force. In Chapter V is a graphical display of 92 times of exposure and their corresponding PK values which were generated during one sequence of battles.

11. Fix Forward

It has long been recognized that it is imperative to repair as many combat damaged vehicles as possible on the battle site in order to reduce the requirement for recovery vehicles and to provide immediate turn-around of equipment to the user. The CODAM Study [5] found that approximately 7% of all combat damaged tanks could be repaired in less than two hours by organizational or direct support maintenance personnel. For PARET, the assumption was made that this 7%

rule could be generalized to all tracked vehicles. At any time that TC (the time available for recovery) is greater than or equal to 2 hours, 7% of the casualties are subtracted from the recovery candidate total. It is obvious that if TC is less than 2 hours some major repair might be accomplished. However, it was felt that the contribution to the reduction of the number of vehicles requiring recovery when TC was under 2 hours would not be significant in this study.

B. MODULE B

Module B performs the following functions which are described in detail below:

a) computes expected number of vehicles recovered

b) computes the loss coefficient

c) computes the number of organizational and DS mobility, firepower, and catastrophic kills (m, f, and k) by type vehicle

d) computes current elapsed time

e) determines when day or night operations must be initiated and makes appropriate parametric changes

1. Expected Number of Vehicles Recovered

This routine is used as a guide to determine the expected number of vehicles which could be recovered in the time available. Recovery vehicle losses are not considered, nor is the daisy chaining technique considered in the computation.

The expected number recovered is determined from:

$$NE = (TC/TR)NR \qquad (4\text{-}17)$$

where TC is the critical time, TR is the time required for recovery, and NR is the number of recovery candidates. Use of this routine is optional and was only included as a guide during the collection of initial statistics. It may be deleted from the program with no effect to other portions of the program.

2. Loss Coefficient

The loss coefficient is the ratio of the number of recovery vehicles lost to the number of vehicles actually recovered. During decision analysis, the loss coefficient is useful as a measure of performance for planning recovery missions. Module B will not be affected by the deletion of this portion of the program.

3. Mobility, Firepower, and Catastrophic Kills

Module A generated a total number of vehicles requiring recovery, but did not distinguish between tanks or TOWS, nor did that module make any distinction as to the type of kill the vehicle received.

As can be seen from the force structure used for the development of the model, tanks make up approximately 40% of the force while TOWs constitute the remaining 60%. These numbers are in the code for this module, and can be changed to suit any situation (see Annex B, Appendix A). In combat

modelling, it is common to classify vehicular kills as mobility, firepower, or catastrophic. An additional classification, personnel kills, is used in some of the high resolution models, but was not considered for this model since that category generally has no effect on recovery requirements when considered alone. Mobility and firepower kills (m and f) are characterized by the vehicle being rendered immobile with still functional fire control and armament systems, or by the vehicle having no remaining armament but still mobile. A catastrophic kill means that the vehicle suffered a combination m and f kill, usually indicating very severe damage.

For the PARET model, the CODAM report [5] was used to provide approximate percentages of m, f, and k kills based on data collected in the 1973 Israeli war. These percentages are in the coding for this portion of the model, and may be easily altered. The CODAM report also provided approximate percentage breakpoints for the level of maintenance which would be required for the recorded kills. Again, these percentages are in the coding for this portion of the module.

As an aid for decision analysis, module B displays the m, f, and k kills and the appropriate maintenance categories for all of the blue casualties, not just those which were designated for recovery by the recovery vehicles. Information on the total number of vehicles is necessary since the decision for which vehicles to recover is generally based on some extent of damage/expected time of turn around criteria

(see Chapter V). After input of the appropriate number signifying desired output for tank or TOW (Appendix A), organizational and then direct support m, f and k kills are displayed.

4. Elapsed Time

Since it was desired to model night operations into the PARET model, it was necessary to monitor elapsed time throughout each sequence of battles. PARET assumes that the red echelon in contact will move forward at the rate of 1 kmh, and that succeeding blue battle positions are 4 km apart (both numbers can be changed through changes in the code). During the time of battle (TB), the red echelon in contact will move TB km. A further assumption is made that the level of blue interdictory fires will remain constant during this phase, i.e. the previously computed interdicted rate of advance (RI) is still valid. With these assumptions, the elapsed time is computed by summing the following equation during each iteration of the model:

$$\text{Time} = \text{TB} + ((1-\text{TB}) + 4)/\text{RI} + \text{TRR} \qquad (4\text{-}18)$$

where TB is the time of battle, RI is the interdicted rate of red advance, and TRR is the time for the red force to rollup and restart. Note that elapsed time will not be computed if module B is not used.

5. Night Operations

Many of the parameters used in PARET must be changed when night operations are modelled. Such things as red rate

of advance, recovery vehicle cross country speeds, mean hookup time and the disorientation factor must be modified if night operations are to be realistically modelled.

The assumption is made that there are no transition periods from daylight to darkness and back again. At time (elapsed) equal to 14 hours, the model immediately makes the transition to night operations, and at time equal to 24 hours daylight operations are again begun. Every 24 hours of elapsed time causes 24 hours to be subtracted from current elapsed time, so the user must be aware that the "clock" resets itself at the beginning of each "day" of combat. The 14 hour point for the beginning of darkness is arbitrary; reference to the coding of this portion of the program indicates the changes to be made for any user defined hour for nightfall. To simulate night operations, the following parameters are internally modified at time equals 14 hours:

- the disorientation factor (D) is increased by 5%
- cross country speed for recovery vehicles is reduced by 50%
- the probability of line of sight is reduced to .1 (higher reliance on IR)
- the mean hookup time is increased by 50%
- the exchange ratio (X) is reduced by 50%

When elapsed time reaches 24 hours, the above parameters are returned to their original values.

It should be apparent that PARET makes daisy chaining a difficult technique to attempt during night operations due to the greatly increased exposure times for the recovery vehicles. Chapter V draws some comparisons between day and night operations in this area. Note that the rate of advance for the red follow-on echelons is a user input parameter for each iteration (battle), and therefore must be manually modified during periods of night operations. For the cases highlighted in Chapter V, the red rate of advance was reduced by 50% during night operations.

C. MODULE C

This module performs the following functions which are explained in detail below:

a) computes the expected time of return for those kills developed in module B

b) computes the number of recovery vehicles requiring either organizational or general support maintenance

c) computes how many recovery vehicles will be operationally ready to begin the next battle

1. Expected Time of Return

From the CODAM data base, the expected times of return of combat vehicles from the appropriate maintenance level based on type kill were extracted and entered into the program coding. Based on kill distribution computed in module B, the CODAM percentages were used as the means of

normal distributions of return times, with various standard deviations based on the maintenance level being considered. If the printer is used with the calculator, expected return times are automatically printed for each vehicle individually; otherwise, a mean time of return is displayed for each category of maintenance. To obtain the mean time of replacements for the blue force, this time is added to the elapsed time previously computed (manual computation).

For the kill distribution, mean return times are generated for all of the blue casualties. Chapter VI points out how this expected return time is one of the primary decision factors which influences which of the casualties will be recovered.

2. Recovery Vehicle Maintenance Distribution

In general, tracked recovery vehicles are allocated very little authorized maintenance at the DS level. As a result, PARET determines only organizational and GS recovery vehicle maintenance requirements. The assumption was made that approximately 30% of all recovery vehicle casualties will be repaired at the organizational level. Using a Monte Carlo approach, this routine determines how many of the recovery vehicle casualties fall into the organizational maintenance category, and that number is displayed as output.

Since total number of recovery vehicles requiring organizational maintenance is displayed without regard to type vehicle, a random number draw technique is used to

determine the type vehicles in the organizational and GS maintenance categories. This random number comparison is a manual computation; another example of sacrificing a "nice to have" routine in order to conserve available memory space.

3. Operational Availability of Recovery Vehicles

It was decided to use actual operational readiness data on recovery vehicles for this study rather than proving ground data. Actual data does not provide a true picture of what would be expected in combat, but does reflect some of the performance profiles for these vehicles under conditions of hard usage. The MMC of the 13th COSCOM, Fort Hood, Texas, provided a compilation of one year's data collected from two armored divisions on the operational availability of the recovery vehicles used in this study.

The user inputs the number of recovery vehicles, by type, which are currently "alive," and the number of vehicles which will be "up" for the next battle is displayed. Based on the number of recovery vehicles which are operationally available for the next battle, decisions have to be made regarding the percentage of self/like recoveries required, whether or not to request the maintenance company M88, or whether recovery will be limited to only certain casualties, i.e. recover only tanks at the expense of TOW recoveries. Chapter VI discusses this problem in detail.

PARET does not directly generate return times from maintenance for the recovery vehicles; rather, it is assumed

that organizational failures will be returned in 20 hours and GS failures will be returned to the unit in 90 hours. Upon return from maintenance, a recovery vehicle is assumed to be in an "up" condition for that iteration. No random maintenance failures of recovery vehicles are played in PARET.

D. MODULE D

Module D forecasts the number of heavy equipment transporters (HET's) which are required in the brigade based on kill distribution developed in module B and the number of vehicles actually recovered. Two computations are performed in this routine: total HET forecast for this battle, and expected return time of the HET's from GS maintenance. No enemy interdiction along the main supply route (MSR) was assumed, and no random maintenance failures were played. Operational availability of the HET's was modelled implicitly into the routine, as explained below.

1. HET Forecast

Note that the basic assumption of this routine is that the number of HET's now organic to a brigade (2) is inadequate. Rather than model the performance of existing assets, PARET determines how many HET's would be required to adequately support the brigade given the kill distribution developed previously. As Chapter V points out, the HET forecast is driven by the red succeeding echelon rate of advance.

Since each tr ¬sporter will be required to carry tanks, TOW's, and at least two types of recovery vehicles, a quantity known as a "HET equivalent" was developed for computational simplicity. HET equivalents for PARET are displayed below. Module C and module B casualties are easily divided among tanks and TOW's by using the relative percentages of these vehicles making up the blue force. For PARET, tanks make up 40% of the force, TOW's 60%. The recovery vehicle loss distribution was computed in module C also. Note that the table below lists an M578 as being one HET equivalent, while in reality it is ½ HET equivalent. By so doing, the operational readiness factor for the HET is implicitly taken into account.

VEHICLE	HET EQUIVALENTS
recovery (any)	1
tank	1
IFV/CFV/APC, etc.	½

TABLE 4-2

Rather than track the exact distance from the MCP to the DS and GS maintenance companies, it was assumed that the DS company would be located 35 km from the FEBA, and would move when the FEBA was within 15 km of its position. Similarly, the GS company was assumed to be located 100 km from the FEBA, and would move when the FEBA was within 50 km

of its position. From [3], a mean time to load a HET was determined, and it was assumed that the offload time would be half of that figure. To account for uneven terrain, the HET road speed was assumed to be 60 kmh unloaded, and 30 kmh loaded. Since the critical time (TC) is the controlling parameter for evacuation operations, the maximum number of trips which can be made to the DS maintenance unit is given by:

$$MD = (TC - TTH)/B \tag{4-18}$$

where TC is the critical time as computed in module A, TTH is the time of travel from the battle site to the MCP, and B is given by:

$$B = TL + TU + DDS/VU + DDS/VL \tag{4-19}$$

Here, TL is the load time, TU is the offload time, DDS is the mean distance to the DS unit, VU is the unloaded speed of the HET, and VL is the loaded speed. If Q is taken to be the HET equivalents going to the direct support unit, then the minimum number of HET's required to evacuate all eligible vehicles to the DS unit is given by:

$$Hmin = Q/MD \tag{4-20}$$

where MD is defined as above.

Due to the travel time involved in moving to the GS unit, it was assumed for this model that only one lift could

be made to the general support unit, i.e. there must be enough HET's to carry all GS evacuation candidates to the GS unit in one lift from the MCP. It is further assumed that the elements of the direct support unit located at the MCP will perform the necessary inspection of damaged equipment, and that they can process a job directly to the GS unit. If this assumption is not played, the number of HET's required for GS evacuation can be subtracted from the overall forecast since all evacuations will then be made from the DS unit. When the GS HET requirement is considered, the forecast for HET's becomes:

$$HMIN = QG - Hmin \qquad (4\text{-}21)$$

where QG is the number of HET equivalents for GS maintenance. Equation 4-21 only holds when QG is greater than Hmin. When this condition is not met, Hmin is taken to be the HET forecast for this battle. PARET produces this forecast independently for each battle. Manual tracking of the HET forecast is required for each battle to determine how many HET's are now on hand versus the number needed from the forecast. When the forecast exceeds the number already on hand, the difference between the two is added to the number on hand. At the end of a complete sequence of battles, the total number of HET's needed for the conditions played in that sequence is known.

2. HET Return Time

Since the assumption was made that enough HET's would be forecast to completely evacuate all casualties to DS and GS maintenance units, and that one lift would be required for GS evacuation, it is only necessary to compute the expected time of return from the GS unit in order to be able to predict how many HET's are on hand at any time. Using a relation similar to 4-19, the time for one complete trip to the GS unit is given by:

$$C = TL + TU + DS/VL + DGS/VU \qquad (4\text{-}22)$$

where TL, TU, VL and VU are as given for 4-19, and DGS is the distance from the MCP to the GS maintenance unit. This time is manually added to the elapsed time to determine the "clock" time for the return of the HET's to the unit. As Chapter V points out, the degree of agreement between the results obtained using this forecasting method and the results obtained from the Battlefield Recovery Study [3] is remarkably close.

The HET forecast developed in this routine is the forecast for the entire number of expected recoveries; self and like recoveries were also considered to have input to the requirements for HET's. To model the recoveries other than those performed by the recovery vehicles, it was assumed that the beginning percentage of self/like recoveries would sustain approximately the same loss rate as the recovery vehicles (even though that was not explicitly addressed in this analysis)

and that the distribution for the various levels of maintenance required would be the same. Then, if N = (1-%self/like), the actual values of Q and QG used in the equations above were obtained from:

$$QG = \text{number of GS casualties}/N \qquad (4\text{-}23)$$

and

$$Q = \text{number of DS casualties}/N \qquad (4\text{-}24)$$

where the casualties in each case were derived from a consideration of the expected number of self/like recoveries and the actual number of recoveries which were input by the user or internally computed.

V. MODEL OUTPUT

A. GENERAL

In order to exercise the PARET model, five "cases" were constructed in which various parametric changes were made to investigate their impact on the recovery and evacuation processes. Five replications of each case were made, and the data presented in this chapter represents the mean output, unless otherwise noted.

The interpretation of the data presented must be made in the light of the specific assumptions used to construct each subroutine, the parameters used for the individual cases, and the tactical scenario used for the model. Small changes in certain key parameters will cause considerable variation in the results obtained.

Portrayed in the graphs and tables which follow are those outputs which seemed most important to analyze for the battle variations considered. A great deal of data was collected during the replications of PARET, but because no clear relationships suggested themselves in that data, it was discarded.

B. CASES CONSIDERED

Listed below are the permanent data base entries used to control the assumptions for the five cases previously mentioned. Appendix A, Annex C gives the detailed listing of the PARET data base locations. All data entered into the

permanent data base (pdb) will remain intact until changed by the user, and the factors listed below for each case must be entered before the first battle of any sequence is fought. As noted in Chapter III, the blue forces move to a new battle position each time the red force reaches its break point, unless otherwise noted.

1. Case 1

Red forces rate of advance: 8 kmh (day), 5 kmh (night)

% self/like recovery: 0%

Distance from recovery vehicle assembly area to battle site: 2 km

Distance to MCP: 15 km

Red breakpoint (% of survivors): 40%

% vehicles unrecoverable: 10%

Allowable blue interdiction of red advance: 0 to 50%

Disorientation factor: 5%

Probability of line of sight: .3

Target priority of recovery vehicles: 5

Vehicle inspection performed at the MCP

Battle site spacing; 4 km

Hookup time distribution: Normal (30 min, 10 min)

Recovery Vehicle cross country speed: 10 kmh

No specific rule for the use of daisy chaining (crew discretion)

2. Case 2

All parameters from case 1 are the same except the following:

Red rate of advance: 3 kmh (day), 2 kmh (night)

% self/like recovery: 40%

Distance to battle site: 1 km

Disorientation factor: 0%

Probability of line of sight: .9

Recovery vehicle cross country speed: 15 kmh

Distance to MCP: 10 km

3. Case 3

All parameters from case 2 are the same except the following:

Red rate of advance: 8 kmh

Distance to MCP: 15 km

No daisy chaining allowed

4. Case 4

Case 4 is identical to case 2, except daisy chaining was allowed only when the expected percentage of recoveries without daisy chaining was less than 85%. Also, red force strength (in contact) was kept continually greater than 200 by allowing more red replacements for each battle. In the three cases above, red in-contact strength was kept below 200 for each battle.

5. Case 5

This case is identical to case 4 except daisy chaining was allowed only when the expected percentage of recoveries using daisy chaining exceeded that without daisy chaining by 20%. Further, the blue force (each battalion team) was required

to stand and fight on its battle position until its strength reached 50% of the original strength. When this breakpoint was reached, that team withdrew to the battle position of the other battalion team, and the combined force stood and fought until it reached the 50% breakpoint. At that point, the problem was ended.

C. RATIONALE

The cases considered for this study represent a wide range of possible parameters for both the blue and the red forces. Those factors which seemed to have the most effect on the outcome of the amount of recovery and evacuation which could be performed were those which were varied.

Case 1 represents a worst case for recovery and evacuation since the red rate of advance is the fastest in this case. The MCP is relatively far from the battle site, disorientation for the recovery crews is allowed, and there is no self/like recovery allowed for this case. Additionally, the recovery vehicle cross country speed is relatively slow. Daisy chaining is left up to the crew's discretion in cases 1 and 2 in order to investigate the differences in performance which occur when some quantitative decision rule for daisy chaining is employed, as in cases 4 and 5.

In case 2, some of the restrictions of case 1 are relaxed, the red rate of advance is slowed, and self/like recovery is played. Both the distance to the battle site and to the MCP

are shortened to investigate the criticality of the travel time to these locations. Based on parametric inputs, case 2 is the "best" case for recovery and evacuation. Note the relationship between the probability of line of sight and the probability of correctly acquiring the target (correct identification after acquisition). With the probability of line of sight set at .9, the assumption is being made that there is no smoke on the battlefield, and that the red force will depend on visual identification rather than infra-red identification. The use of visual identification will keep the adjusted time of exposure short, and therefore, recovery vehicle survivability high.

Case 3 increased the red rate of advance, moved the MCP farther from the battle site and forbade the use of daisy chaining. Direct comparisons with case 1 are possible, bearing in mind the other parametric changes carried forward from case 2.

Cases 4 and 5 are similar in that they both play quantitative rules for the decision to use daisy chaining during recovery. A slow red rate of advance is used, and the MCP is relatively close to the battle site. The primary area to be investigated in these two cases is the effect of introducing some decision logic on the recovery tactics. Also note that the red force level is kept at a higher level than in the previous cases in order to generate more blue casualties and produce a longer time of battle. Case 5 investigates what

the effect of changing the blue combat tactic is on the recovery and evacuation effort.

All possible variations of the parameters in the model have not been investigated for this study. Rather, those which seemed significant were allowed to change. The worst and best cases of those listed above provide some striking contrasts in the measures of performance for recovery and evacuation to be discussed below.

D. ANALYSIS

Figure 5-1 displays a set of data collected from one run of case 1. The graph shows the effect of increasing time of exposure relative to the probability of being killed. Note that this probability of kill is that for the battle site computation, based on the methodology presented in Chapter IV. Case 1 used a probability of line of sight of .3 which slightly inflates the time of exposure, hence the PK for case 1 will be slightly higher, on the average, than that for case 2. The general shape of the PK curves for all cases will be the same.

Figure 5-1 was generated from 92 data points. It is significant that the PK was less than .33 in 71% of the cases presented here. FM 71-100, Armored and Mechanized Division Operations, presents a probability of first round kill chart (page 2-9) for the SAGGER weapons system firing at M-60 tanks. At 1 km, the SAGGER has a probability of first round kill on

EXPOSURE TIME VERSUS PROBABILITY OF KILL

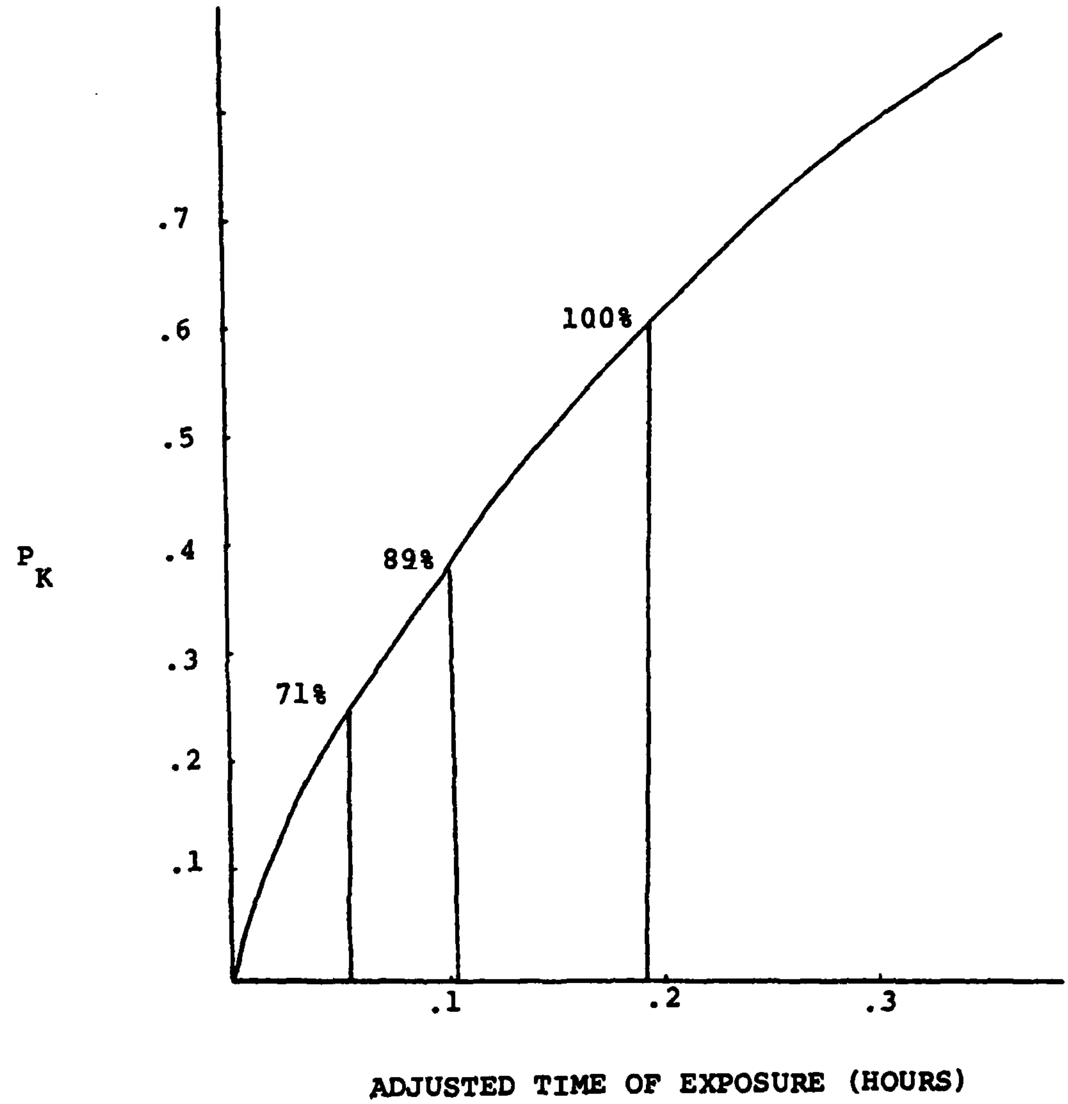

FIGURE 5-1

an M-60 in hull defilade of .28. Since the recovery vehicles will be operating behind the weapon systems they are retrieving, it seems reasonable to assume that the presented target area of the recovery vehicle should be not greater than a tank in hull defilade. PARET, then, agrees remarkably well with established doctrine for the probabilties of kill for recovery vehicles on the battle site under the modelling assumptions used.

PARET automatically keeps track of total elapsed time during its execution, and battle time is displayed during each iteration and so can be manually tabulated. From this data it is possible to determine an approximate conversion factor from battle time to elapsed time for use in analyzing other models. Since red divisions were assumed to have the same spacing as the regiments in the cases investigated, in order to express elapsed time based on a more realistic divisional spacing it was necessary to assume that the red divisions were separated by 20 km. Using a mean interdicted rate of advance, and by determining how many red divisions would have been engaged in a particular sequence of battles, an "adjusted" elapsed time was computed. The total distance moved across the battlefield was also tallied, and so an actual red rate of advance for any sequence of battles is easily computed. Table 5-1 displays data from several cases which compares the blue tactic, red rates of advance and elapsed times. For this discussion, tactic 1 is the bounding

retrograde tactic which causes the blue force to displace to an alternate battle position each time the red force reaches its break point. Tactic 2 requires the blue force to stand and fight until it reaches 50% of its original force, then it withdraws to the battle position of the other battalion team.

TACTIC	RA	ELAPSED TIME	ADJ TIME	ACTUAL RA	ADJ RA
1	8 kmh	28.3	39.6	1.41 kmh	1.01 kmh
1	3	76.8	116.8	.573	.377
2	3	42.7	72.7	.562	.330

TABLE 5-1

The use of tactic 1 allowed the red forces to move a mean distance of 42 km during the sequence of battles, while the use of tactic 2 allowed the reds to move only 24 km on the average. These distances were used to derive the actual and adjusted rates of advance listed above. For the 8 kmh rate of advance cases, the blue tactic used is immaterial since little recovery can be performed due to the rapid movement of the FEBA produced by red momentum. If the red rate of advance can be held to a low value through interdictory fires, the blue force can be expected to hold out reasonably long based on the assumptions used for the model. Reference 3 states that the blue forces can fight a delaying action for approximately four days if the red rate of advance is .5 kmh. PARET shows very good agreement with those numbers.

In Table 5-2, the mean number of recovery vehicle losses by type are displayed for each of the cases. Recall that cases 1 and 3 portrayed an 8 kmh rate of advance for the red succeeding echelons, and a distance of 15 km to the MCP. The table displays total losses by type; during the exercise of the model, statistics were collected on the percentage of losses during movement versus those lost on the battle site during the actual recovery. Of all recovery vehicle losses, 70% occurred on the battle site itself (direct fire attrition). A 30% loss rate due to indirect fire is high, but only because PARET assumes a hit is identical to a kill. When vulnerability data for direct and indirect fire becomes available, PARET can be modified to reflect the change, and the percentage of all kills should shift more significantly toward the direct fire attrition. Other forms of interdiction of the recovery vehicles during movement can be played by using a stochastic modification in the routine which controls the probability of kill during movement.

Chapter VI details the decision factors used for the allocation of the recovery vehicles to specific missions. That decision process included not committing the M553 vehicles until all, or nearly all, of the M578 vehicles were inoperative or dead; the M553 loss rate is correspondingly low in Table 5-2 for that reason. It was assumed that each battalion team had 7 M88's, 4 M578's and 4 M553's at the beginning of any sequence of battles. The aggregated loss

rates depicted in the table reflect multiple losses, i.e. some of the recovery vehicles which were returned from maintenance were killed again (cases 1, 2 and 3). A high resolution model could keep track of recovery vehicles by bumper numbers, thus providing more detailed output reflecting which vehicles actually received multiple kills.

TOTAL RECOVERY VEHICLE LOSSES (BY TYPE)

CASE	M88	M578	M553
1	17	8	3
2	13	12	2
3	15	7	2
4	11	7	2
5	9	7	3

TABLE 5-2

All models now in use quantify the response of the variable under study through the use of some measure of performance (MOP). A natural MOP for a model which investigates recovery and evacuation is the number of vehicles actually recovered versus those vehicles which were recovery candidates. The number of vehicles actually recovered is determined based on the number of recovery vehicles sent on the mission, how many were killed, and whether or not daisy chaining was being used for the mission. Table 5-3 shows the number of tanks and TOW's which were recovered by

recovery vehicles versus how many were candidates for recovery as determined by the model. The data reflects the intuitive result that the red rate of advance is the controlling parameter for recovery operations, at least in a formulation which does not play random maintenance failures of the recovery vehicles. In those cases where the probability of line of sight was high, or when the distance to the MCP was relatively short, the percentage of recovery was higher overall. This data agrees well with that found in Reference 3.

It is interesting to note that the highest percentage of recovery occurred when the fixed percentage rule (case 4) was enforced. Case 1 allowed daisy chaining at the discretion of the crew, and the red advance rate was 8 kmh; by contrast, case 3 forbade daisy chaining at the same rate of advance, and the percentage of recovery more than doubled. Although this outcome seems to indicate that the recovery tactic used is also directly related to the red rate of advance, more replications of each of these specific cases would be needed to confirm these results. Case 5 employed decision criteria centering around a difference in expected percentages of recovery using both methods; this logic does not seem quite as reliable as that used for case 4, but recall that the blue force's tactics were also modified for case 5. Chapter VI enumerates the recovery priority system used in the model, and this accounts for the lower percentage of TOW's recovered versus the tanks.

NUMBER RECOVERED VERSUS NUMBER OF CANDIDATES

CASE	TANK	%	TOW	%
1	13/82	16	6/123	5
2	36/53	68	19/75	25
3	19/50	38	15/73	21
4	37/45	82	9/68	13
5	26/55	47	8/83	10

TABLE 5-3

Case 1 losses appear higher in the table because the percentage of self/like recovery was set a 0. The distribution of recovery vehicle losses by type also influences what the actual mix of recoveries will be; i.e. an M88 can recover anything on the battlefield, but the M578/M553 vehicles are limited to the lighter vehicles.

The number of vehicles returned to the user during a sequence of battles is totally dependent on the elapsed time achieved during the sequence. Elapsed time is a function of the tactics being employed, the effectiveness of the recovery effort, and the red rate of advance. Table 5-4 depicts the mean number of vehicles of all types returned to the user before termination of the sequence of battles. Case 2 produced the highest number of returnees to combat, and this was an intuitive result since case 2 was the best case by design. Even though case 4 had the best recovery percentage of all the cases, the number of vehicles returning to combat

is low because in this case and in case 5, the red force was kept at a higher level for each engagement than for the other cases. This higher red force level caused elapsed time of the sequences to be shorter since the blue force was brought to its break point in a much faster time. Note also that the 8 kmh rate of advance has nearly the same effect on the number of vehicles returning (cases 1 and 3) as increasing the size of the opposing force. Due to the underlying Lanchester basis of PARET, elapsed time is shortened by either increasing the opposing force or by increasing their rate of advance. Recall that it was assumed that the basic red force tactic centered around momentum, and momentum has only two components: mass and speed.

NUMBER OF VEHICLES RETURNED TO BATTLE

CASE	M88	M578	M553	TANK	TOW	TOTAL
1	4	0	0	8	4	16
2	4	6	0	20	15	45
3	2	2	0	7	6	17
4	1	1	0	9	7	18
5	3	0	0	14	5	22

TABLE 5-4

One of the most troublesome areas in the interpretation of output from a model is the relation of battle time (time in combat) to elapsed time, or "clock" time. Using the

adjusted time data produced in Table 5-1, Figure 5-2 shows the relationship between battle time and elapsed time. Data for tactics 1 and 2, and for the 3 and 8 kmh rates of advance are shown.

Chapter IV discussed the rationale used in forecasting the number of HET's required for a combat brigade involved in a delaying action. Reference 3 determined that the brigade would require 7 HET's to perform evacuation to the various levels of maintenance. Table 5-5 shows the results of the PARET forecasting routine for determining the HET requirement. The number of HET's required is more directly dependent on the rate of advance of the red force than on any other single parameter. This result is intuitively appealing since less recovery can be performed when the opposing force is approaching at a higher apparent speed.

EXPECTED NUMBER OF HET'S FOR THE BRIGADE

CASE	HET'S
1	4
2	7
3	6
4	7
5	8

TABLE 5-5

If it can be assumed that the red force will move at 3 kmh, then the 7 HET's determined to be required by Ref. 3 appears to be a reasonable estimate.

CUMULATIVE BATTLE TIME VERSUS ELAPSED TIME (ADJUSTED)

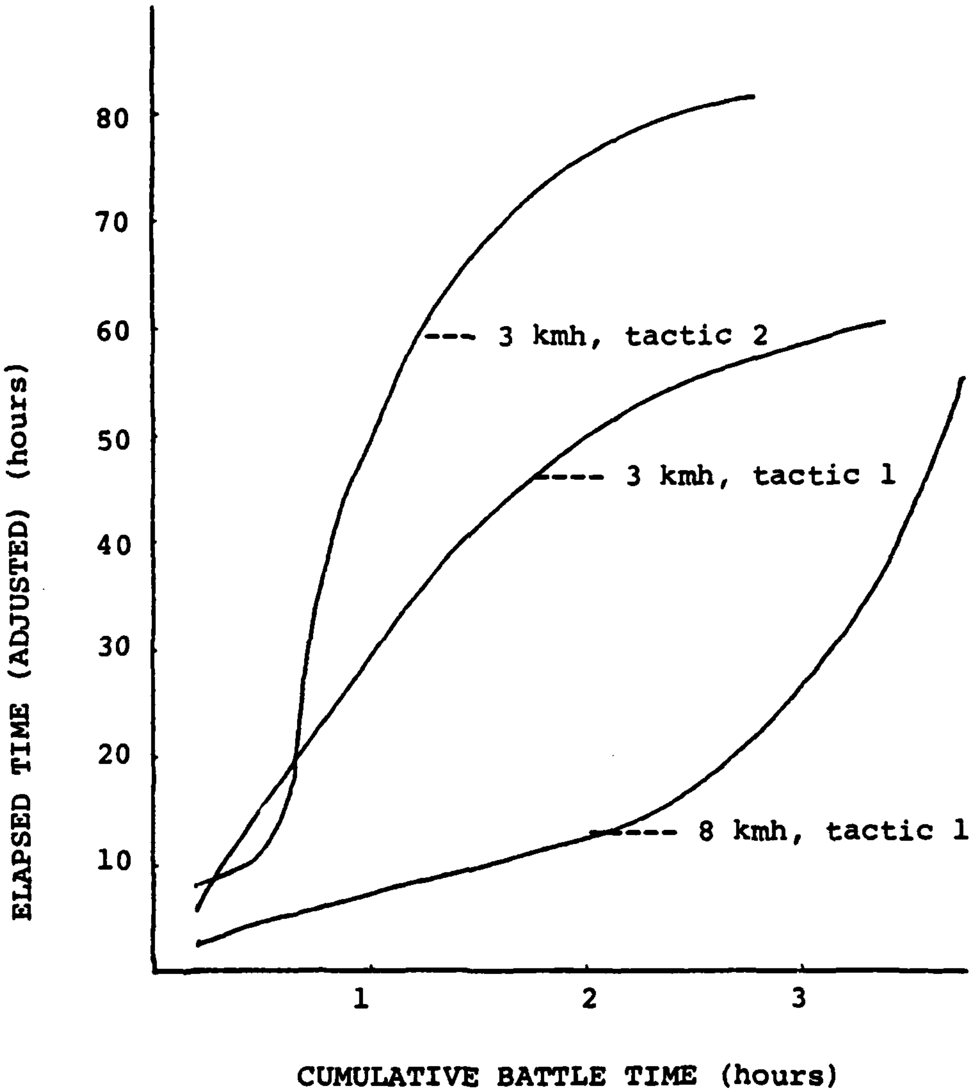

FIGURE 5-2

As was mentioned in the beginning of this chapter, many more statistics were collected during the many runs of each of the cases presented here. Most, however, were used to gain insight into how the model worked and how the various parameters are inter-related in the recovery and evacuation process. An effort was made to distill the insight gained from using the model into one concise group of data representative of most of the key issues facing the logistics community in looking for solutions to the recovery and evacuation problem.

VI. DECISION LOGIC

This chapter investigates the parameters used for decision making in the PARET model. The combat processes leading up to the recovery and evacuation processes have been modelled simply; red and blue forces stand and fight until one or the other reaches some pre-determined breakpoint. In a general sense, that breakpoint represents the point at which the unit ceases to be an effective fighting force, based on some subjective decision process the modeller has used. A combat unit does not reach a state of ineffectiveness instantaneously as the model presupposes; the commander on the ground must go through a great deal of analysis of various factors before he reaches the decision that his unit no longer can be called upon to effectively counter the enemy.

Just as the basic decision on combat effectiveness can be modelled through a quantitative factor, so too some of the decision processes involved in the recovery and evacuation of combat vehicles can be modelled easily. One of the primary uses of the PARET model is the investigation of the decision factors leading to successful recovery, evacuation of the damaged equipment, and eventual return of the equipment to the user. This chapter highlights what decision rules were used in the cases discussed in Chapter V.

For simplicity, it was assumed that no recovery missions would be rejected. In actuality, missions would be rejected

for factors such as too great a perceived threat, no recovery vehicle crews, or the number of operational recovery vehicles being below some pre-set level. These factors are easily modelled in a high resolution model, and will not be dwelt upon here.

The decision process used in PARET is described below. All of the factors influencing the decision to recover or not to recover would take a great deal of time to fully uncover and model; those listed here are considered to be those which must be dealt with first, i.e. those which constitute the "heart" of the recovery and evacuation decision process. For clarity, the factors to be discussed are introduced in the form of a series of questions.

A. IS THERE ENOUGH TIME TO RECOVER THE ENTIRE GROUP OF RECOVERY CANDIDATES?

Comparison of the expected time to recover the force and the time available for recovery (critical time) must be made. If self/like recovery is being used, it may be necessary to raise the percentage of vehicles recovered in this manner if time is the over-riding constraint on the system. In the event that self/like recovery is infeasible or cannot be increased, a decision must be made on the number of vehicles which will be recovered. It is also possible that the implementation of the daisy chaining technique will allow all, or almost all of, the candidates to be recovered. For the cases

considered in Chapter V, the percentage of self/like recovery was held constant, and daisy chaining was only used when certain percentage criteria were met (in the cases which imposed rules on recovery tactics). Decision logic to vary the percentage of self/like recovery, or to impose daisy chaining based on some time ratio parameter is easy to incorporate in a model in order to optimize the percentage of vehicles recovered.

B. WHAT IS THE PRIORITY FOR THE RECOVERY OF VEHICLES?

The PARET model lists kills by their category of maintenance and the type kill. Additionally, the expected time of return from maintenance is an output parameter. For all cases considered, the following priority for recovery was assigned to vehicles: tanks, M88's, TOW's, M578's, M553's. The vehicles with the shortest expected turn around time from maintenance were those recovered in each category, dependant on what recovery vehicles were available to use. Such a subjective prioritization is mandatory in order that the time available for recovery can be optimized. It has been implicitly assumed that at least enough information from the vehicle crews will be made available to the recovery teams so that some idea of the extent of damage will be available before the recovery mission is launched. This will probably not be the case; the recovery crews will have to make an evaluation of the extent of the damage at the battle site, and recover those vehicles which fit the priority scheme.

Due to the time-based nature of this model, it is assumed that initial vehicle inspection will be performed at the MCP, not the battle site. Again, perfect information flow is being implicitly assumed. Incorporation of the "7% rule" makes the prospect of less-than-perfect information flow easier to cope with since it can be assumed that the organizational maintenance personnel on the battle site will have performed at least a cursory inspection of the damaged equipment, and can therefore provide the recovery crews with a representative idea of which vehicles are the most likely recovery candidates.

C. HOW MANY RECOVERY VEHICLES SHOULD BE SENT FORWARD?

If the mission is not refused, there are three alternative answers for this question: send one recovery vehicle for each damaged vehicle, send all available recovery vehicles on every mission, send recovery vehicles up to some predetermined "safety level."

Alternatives one and three are easily incorporated into a model. PARET used alternative two whenever possible. In a high resolution model, it might be desirable to allow the shifting of recovery assets so that the unit in contact has only operational recovery vehicles at its disposal. PARET played no cross-leveling of assets but did allow the unit in contact to request the M88 from the maintenance company attached to the brigade. Unless lost in combat, that additional M88 was assumed to be always "up," and no time was assessed to move it up to the battle site.

D. WHEN SHOULD DAISY CHAINING BE EMPLOYED?

In a model which does not use exposure time for the parameter used for determining the probability of kill, daisy chaining does not impose as serious a penalty as in the PARET model. Cases were studied in Chapter V which allowed the crew to decide to use daisy chaining at their discretion, and some cases in which quantitative rules were imposed before daisy chaining would be allowed.

From the analysis presented in Chapter V, it appears that the use of some expected percentage of recovery for the decision rule is the more viable rule. When exposure time is not being considered, the decision rule should center around a comparison of the time available for recovery versus the time necessary to daisy chain, all, or part of, the recovery candidates off the battle site. Current doctrine requires daisy chaining whenever possible; the interpretation of "possible" is the decision rule to be modelled in the context of the individual model's parameters.

E. HOW SHOULD CREW AVAILABILITY BE MODELLED?

For the purpose of simplicity, PARET assumes total crew availability for the recovery vehicles. In the case of the high resolution model, the percentage of a crew lost when a recovery vehicle sustains a kill must be specified. Continuous operations must be modelled in such a way that crew availability will be degraded over time in much the same way as

combat effectiveness is lost in the fighting unit. The combination of attrition and constant operations can be assumed to render a large part of the remaining recovery fleet inoperable after only a few days of combat.

Through the same reasoning, the performance of the maintenance elements will degrade over time. This phenomena can be easily modelled through an inflation of the expected turn around time from maintenance for each succeeding day of combat. Similarly, lengthening of the expected times for recovery can be used to model the decreasing effectiveness of the recovery crews.

F. HOW MUCH OF THE RECOVERY FORCE SHOULD BE ALLOCATED FOR CONTINGENCY MISSIONS?

One of the contingency missions which will affect the availability of the recovery assets will be the need for a heavy lift capability at the MCP. Requests may be received for the recovery of allied equipment in other sectors of the battlefield, or for the recovery of higher priority equipment in the division.

To the author's knowledge, no high resolution models exist which play logistic activities to this level of resolution. The "safety" level of recovery vehicles referred to previously could be used to provide support for these contingency missions. A set of rules that allocate recovery vehicles to missions other than recovery of damaged equipment would require

a great deal of subjectivity on the part of the modeller, and would necessarily have to be flexible enough to allow easy change of the parameters.

This chapter has not covered all of the decision factors which must enter into the complex area of recovery and evacuation. Those which have been presented, however, form the basis of what is essential as a solid base from which embellishments can be made to enhance the performance of the model. Careful, step-wise development of logistics models will eventually provide the same level of detail for the combat subfunctions as the pure combat models have achieved.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis has presented an analytical approach to modelling one of the combat subfunctions. Rather than using the traditional approach of using a large, computer based simulation, a parametric model for use in the hand-held calculator was developed.

Battlefield recovery encompasses the retrieval of combat damaged vehicles, and also those which become random maintenance casualties, or those which become mired on the battlefield. Only the first case of vehicles was considered in the model; the inclusion of the other classes of recovery candidates into the model could be easily accomplished. If the activities surrounding the act of recovery are understood, breakdowns and mired vehicles become an extension of the basic process.

PARET was developed to be played in a defensive environment in order to model the maximum amount of stress on the underlying logistics system. By allowing the red force to be virtually unlimited in size, it was possible to study the blue recovery and evacuation tactics in great detail when system capabilties were stressed to the breaking point. All cases discussed in Chapter V proved that recovery can be accomplished in a relatively timely manner, given that the

basic model assumptions are correct and reasonably represent the "real" world.

Analysis of the effects of the red succeeding echelon rates of advance indicates that not only is the recovery effort controlled by that parameter, but also the location of the MCP and combat trains must be carefully considered in the light of the expected red rate of advance. When the red rate of advance is between 5 and 8 kmh, the MCP must be at least 15 km from the FEBA to preclude being over-run. Slower rates of advance would allow closer proximity for the MCP. The maintenance units are not as sensitive to the rate of advance, but care must be taken to insure that their placement allows 2 to 3 days of uninterrupted support before they have to displace. At the faster rates of advance, the DS maintenance unit should be located 40 to 50 km from the FEBA, based on the PARET model. Support from the maintenance units is in direct proportion to their stability; more displacements to avoid the enemy will result in lower levels of support, which in turn will cause the blue force to reach its breakpoint sooner.

Although PARET did not forecast the number of recovery vehicles required for the brigade as was done for the HET's, the recovery rate at the higher rates of advance indicates that additional recovery vehicles is the only alternative to implement to achieve higher recovery rates in the same time. There will be a point of marginal returns in increasing the

the number of recovery vehicles on the battlefield due to the increased level of confusion caused by any substantial increase in numbers.

B. RECOMMENDATIONS

The following recommendations are made: a) that follow-on research be conducted to model the maintenance subfunction, from the MCP to the supporting maintenance unit, and back to the user; b) that recovery and evacuation be included in existing high resolution combat models; and c) that strong consideration be given to the development of a logistics "library" module for the hand-held calculator. Such modules are capable of storing 5000 program steps, and would obviate the need for using the magnetic card system for models like PARET. The United States Army Field Artillery School has had a module constructed for them by Texas Instruments for the TI-59. That module is used in the fire control area exclusively, but lends credence to the feasibility of the hand-held calculator as an analytical tool for field use.

It is hoped that the methodology used for the PARET model has provided an investigative tool for the battlefield recovery and evacuation studies which are now being conducted, and for those to be conducted in the future.

APPENDIX A: USER'S MANUAL

This appendix is arranged in three annexes which cover the following material: Annex 1: use of the model, Annex 2: program listing, and Annex 3: data base listing.

In its present form, PARET is contained on five program cards and one data card. It is possible to compress the model onto fewer cards once its operation is fully understood; however, by keeping the model on these five cards, the user will find program editing is much easier with the built in extra room on each card.

Note that the data base card contains not only the permanent data base, but also the intermediate data base. The permanent data base remains unaltered throughout execution, while the intermediate data base is continually changed during the operation of each program module. Care must be exercised in the interpretation of data extracted from the base since values in various memory registers will be changed during execution of the program. Annex 3 delineates both the permanent and intermediate data bases and indicates what values are in the intermediate base depending on which module is being used.

The program listing in Annex 2 contains some non-standard symbols for various key strokes to facilitate typing. These are completely explained in that Annex, but the user should

note that these symbols will not be what he would see if the program is listed using a printer.

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A PARAMETRIC ANALYSIS OF THE TECHNIQUES USED FOR THE RECOVERY A--ETC(U)

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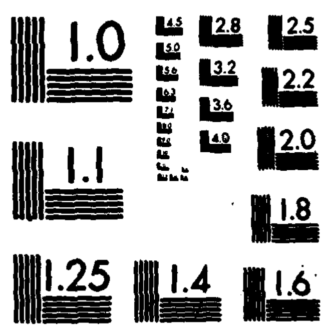

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

ANNEX 1: USING THE PARET MODEL

In the description below, it is assumed that the user has some previous experience using the TI 59 programmable calculator. For example, explicit instructions for reading cards into the memory set will not be given. Should problems be encountered, the reader should refer to Personal Programming, the TI 59 manual supplied with the machine.

The program modules use the following numbered cards:

Module A: cards 1 and 2

Module B: card 3

Module C: card 4

Module D: card 5

Data Base: card 6

Refer to this listing when using the instructions below. Card 6 is read into memory at the beginning of a model run and should not be repeated once a sequence of battles has begun since data is continually generated during execution. Note also that the program does not contain the commands clear (CLR) or reset (RST), and these commands should not be given from the keyboard during execution. Flags are used throughout the program, and either of these two commands will reset all flags which have been set. For example, the subroutine which senses day and night conditions uses a flag; if clear or reset are given from the keyboard during a night phase, the model will

change to daylight operations and will subtract 24 hours from the displayed time.

The following conventions will be used to list the steps required for the use of each module: data (key) display. When no data is required as input for a step, or when the display has no meaning, those positions will be left blank for that step. XT refers to the "x exchange t" key on the keyboard, and this convention will also be used in the program listing, Annex 2.

1. Module A

a. read in card 6 (banks 3 and 4)

b. read in card 1

c. (E') 0 initializes calculator, only do for first battle of a sequence

d. red starting force (A) red starting force

e. blue starting force (R/S) battle time

f. rate of advance (B) interdicted rate of advance

g. distance to battle site (C)

h. distance to maintenance colleciton point (R/S)

i. (D) critical time

j. (E) number of vehicles to be recovered by recovery vehicles

k. (R/S) blue survivors

l. (XT) red survivors

aa. read in card 2

bb. number of recovery vehicles available (A') expected

time to recover force

cc. (B') expected percentage recovered without daisychaining

dd. (R/S) expected percentage recovered using daisychaining

ee. (A') expected time to recover the force with daisy-chaining (this is an optional step, and is only done when the decision is made to daisychain)

ff. (C') number of recovery vehicles killed during the movement phase

gg. (XT) number of recovery vehicles killed on the battle site

2. <u>Module B</u>

a. read in card 3

b. (A) total elapsed time

c. (B) maximum number of recoveries possible in the time allowed

d. number of vehicles recovered (C) loss coefficient

e. 1 for tank or 2 for TOW (D) number of m,f and k kills by level of maintenance (after first number is displayed, R/S will display succeeding numbers for organizational and then direct support maintenance)

f. (A') total elapsed time (this step is necessary to clear a fixup taken in step e, and also determines whether to play day or night parameters based on total elapsed time)

Note: If the printer is used with the calculator, the output from step e is automatically listed in the order given above, i.e., first organizational and then direct support m,f and k kills.

3. Module C

   a. read in card 4

   b. (A) expected return times for organizational m,f and k kills (use the R/S method to obtain all times for this step and step c, as was done for step e above)

   c. (B) expected return times for direct support m,f and k kills

   d. (C) expected number of recovery vehicles requiring organizational maintenance

   e. type recovery vehicle (1=M88, 2=M578, 3=M553)(D)

   f. number recovery vehicles available (E) number recovery vehicles "up" for next iteration

4. Module D

   a. read in card 5

   b. number recovery vehicles expected to go to GS maintenance (A)

   c. number vehicles actually recovered (R/S) number of HET's required

   d. (B) expected time of return of HET's to the MCP

While using the model, the user must track some of the output variables manually since the program is not designed to provide summary statistics in all cases. For example,

the HET requirement generated in module D does not automatically decide the requirement based on present time. The output from step c above only takes into account the situation it is presented with in making the determination; the user must manually track how many HET's are currently at the MCP and make the determination as to how many additional HET's will be required. Similarly, the expected return times from maintenance are not expressed in "real" time, but rather in the number of hours to return; the user must add present clock time to that number to determine the time of return of the combat vehicles in real time. These modifications to the program, although simple to make, were not done in order to conserve space in the calculator.

Standard partitioning (479.59) was maintained throughout the model, but if the user decides to leave the model in its present spread-out form, repartitioning would be desireable in some cases to add the features mentioned above. Also note that this version of PARET was designed around the Applied Statistics Module, but to use the Master Library Module, the only change which must be made in the codeing is to change every "PGM 05" to "PGM 02." If this change is not made, and the Master Library is used, some portions of the model will not work at all, and those which do will produce extremely unreliable output.

ANNEX 2: PROGRAM LISTING

Listed below is the program for the PARET model. Since each card is designed to perform various functions, the program is listed by card rather than by module. Some of the keystrokes from the calculator are not directly reproduceable here, so the following conventions will be used for those cases:

XT = x exchange t

GE = x greater than or equal to t

LT = x less than t

PR = polar to rectangular

SQRT = square root of X

SQ = x squared

ABS = absolute value of x

* = multiplication

** = division

All other keystrokes can be easily reproduced and will be written as they would appear when using the printer with the calculator. The program is listed left to right; the number at the beginning of each line refers to the last command on that line, and is the location in program memory for that command.

1. Card 1

Labels Used:

A(001), B(063), C(079), D(103), E(135), LNX(171), TAN(195),

EXC(208), ((221), SUM(235), E'(251), A'(257)

Flags Used: None

```
LBL A STO 27 R/S STO 28 SBR ( RCL 27 ** RCL 28 ) STO
07 SQ * ( 1 - RCL 32 SQ ) ) +/-+ RCL 30 ) STO 00 OP 10
XT 0 GE A' RCL 00 SQRT + (RCL 32 * RCL 07 +/- ) ) **
( RCL 30 SQRT - RCL 07 ) ) LNX ** RCL 30 SQRT ) STO 08
R/S LBL B STO 14 3 5 STO 20 RCL 34 SBR SUM INV PRD 14
R/S LBL C ** RCL 36 ) STO 15 RCL 37 * RCL 15 ) SUM 15
) R/S ** RCL 36 ) STO 16 R/S LBL D 5 + RCL 08 ) - RCL
08 * RCL 14) ** RCL 14 ) STO 17 4 1 STO 20 RCL 40 SBR
SUM SUM 17 RCL 08 + RCL 17 ) STO 18 RCL 30 X RCL 08 ) *
( RCL 27 * (1 - RCL 32) ) ) +/- SUM 18 RCL 18 R/S LBL
E RCL 28 - (RCL 27 - RCL 32 * RCL 27 ) ** RCL 30 ) )
STO 26 RCL 28 - RCL 26 ) STO 19 2 XT RCL 18 GE TAN LBL
LNX RCL 19 * RCL 33 ) INV SUM 19 RCL 19 * RCL 42 ) INV
SUM 19 RCL 19 GTO EXC LBL . 0 7 * RCL 19 ) SUM 26 GTO
LNX LBL EXC R/S RCL 27 * RCL 32 ) XT RCL 26 R/S LBL
( RCL 56 * RCL 28 ) +/- INV LNX STO 30 RTN LBL SUM PGM
02 A RC* 20 PGM 02 B PGM 02 C RTN LBL E' 0 STO 57 RTN
LBL A' RCL 30 SQRT 1/x +/- * ( 1 - RCL 32 ) LNX ) STO
08 RTN
```

2. **Card 2**

Labels Used:

A(001), LOG(027), PR(049), SIN(110), SQRT(120), SQ(126), CE(144), SUM(153), C(169), +/-(177), 1/X(189), EE(232), B(245), A'(303), FIX(323)

Flags Used: 2 and 3

Program:

```
LBL A STO 07 STO 22 SBR SQRT RCL 19 ** RCL 07 ) STO 21 *
2 - 1 ) STO 23 IFF 03 FIX LBL LOG RCL 23 * ( RCL 39 +
RCL 16 ) ) + RCL 23 * RCL 16 ) + RCL 15 ) STO 51 RTN LBL
PR 4 6 STO 20 RCL 45 SBR SUM +/- + 1 ) STO 23 SBR CE RCL
39 * RCL 50 ) + RCL 23 * RCL 39 ) STO 24 * RCL 00 ) +/-
SUM 24 RCL 43 PRD 24 RCL 24 LNX 1/X ABS STO 25 SBR SIN
DSZ 07 PR RCL 59 STO 58 RTN LBL SIN SBR CE XT RCL 25
GE SQRT RTN LBL SQRT 1 SUM 59 RTN LBL SQ RCL 29 PGM 02
A RCL 41 PGM 02 B PGM 02 D STO 39 RTN LBL CE PGM 02 SBR
DMS STO 00 RTN LBL SUM PGM 02 A RC* 20 PGM 02 B PGM 02 C
RTN LBL C INV STF 03 0 STO 52 LBL +/- 0 STO 59 DEG RCL
15 TAN SQRT STO 25 LBL 1/X SBR SIN DSZ 07 1/X RCL 59
SUM 52 IFF 02 EE STF 02 RCL 22 - RCL 52 ) STO 07 SBR
PR RCL 22 - RCL 52 - RCL 58 ) STO 07 RCL 16 STO 15 GTO
+/- LBL EE INV STF 02 RCL 58 XT RCL 52 SUM 58 RTN LBL
B RCL 18 ** RCL 51 ) * RCL 19 ) STO 54 RCL 18 * 2 )
STO 24 RCL 51 + RCL 51 * . 5 ) STO 25 RCL 24 ** RCL 25 )
* RCL 19 ) STO 55 RCL 54 ** RCL 19 ) RTN RCL 55 ** RCL
19 ) R/S LBL A' STF 03 RCL 21 STO 18 2 PRD 39 1 . 5 PRD
16 RCL 07 A RTN LBL FIX 2 INV PRD 23 GTO LOG RTN
```

3. <u>Card 3</u>

<u>Labels Used:</u>

B(001), $\bar{X}$(033), C(38), DEG(049), D(065), LNX(079), ((087), A'(243), CLR(259), SQ(294), **(305), Y^X(344), A(347)

Program:

LBL B . 3 3 STO 14 . 5 8 STO 15 RCL 18 ** RCL 51) * RCL 19) STO 59 RCL 19 XT RCL 59 GE X RTN LBL X RCL 19 RTN LBL C STO 59 RCL 58 ** RCL 59) R/S LBL DEG RC* 20 PGM 02 A RCL 21 PGM 02 B PGM 02 D RTN LBL D XT 1 EQ LNX RCL 19 * . 6) GTO (LBL LNX RCL 19 * . 4) LBL (STO 25 1 4 STO 20 . 1 STO 21 SBR DEG * RCL 25) STO 23 4 7 STO 20 SBR DE * RCL 23) STO 08 4 8 STO 20 SBR DEG * RCL 23) STO 16 RCL 23 - (RCL 08 + RCL 16)) STO 17 RCL 08 PRT ADV RCL 16 PRT ADV RCL 17 PRT RCL 25 - RCL 23) STO 25 1 5 STO 20 SBR DEG * RCL 25) STO 23 4 7 STO 20 SBR DEG * RCL 23) STO 54 4 8 STO 20 SBR DEG * RCL 23) STO 24 RCL 23 - (RCL 54 + RCL 24)) STO 25 RCL 54 PRT ADV RCL 24 PRT ADV RCL 25 PRT RCL 08 FIX 00 RTN RCL 16 R/S RCL 17 R/S RCL 54 R/S RCL 24 R/S RCL 25 R/S LBL A' INV FIX IFF 01 SQ 1 4 XT RCL 57 GE CLR GTO Y^X LBL CLR STF 01 . 0 5 SUM 37 2 INV PRD 36 RCL 43 * 1 0) STO 31 INV PRD 43 . 3 SUM 29 . 5 INV SUM 30 GTO Y^X LBL SQ 2 4 XT RCL 57 GE ** GTO Y^X LBL ** . 0 5 INV SUM 37 2 PRD 36 RCL 31 ** 1 0) STO 43 . 3 INV SUM 29 . 5 SUM 30 INV STF 01 RCL 57 - 2 4) STO 57 LBL Y^X RTN LBL A RCL 18 + ((5 - RCL 08) ** RCL 14)) SUM 57 RCL 57 RTN

4. Card 4

Labels Used:

A(001), EXC(027), PRD(061), COS(098), DEG(128), SUM(144),

B(151), SIN(172), ENG(209), LOG(246), C(276), TAN(285), RAD(299), Y^X(306), D(311), LNX(326), 1/X(334), E(342), PR(361)

Flags Used: None

Program:

LBL A 0 STO 00 07 RCL 08 INT STO 08 . 5 STO 21 6 . 4 4 STO 23 2 3 STO 20 LBL EXC SBR DEG PRT ADV OP 20 SUM 07 DSZ 08 EXC RCL 07 ** RCL 00) STO 44 0 STO 00 STO 07 RCL 16 INT STO 08 4 STO 23 LBL PRD SBR DEG PRT ADV OP 20 SUM 07 DSZ 08 PRD RCL 07 ** RCL 00) STO 19 0 STO 00 STO 07 RCL 17 INT STO 08 2 1 . 1 STO 23 LBL COS SBR DEG PRT ADV OP 20 SUM 07 DSZ 08 COS RCL 07 ** RCL 00) STO 22 RCL 44 RTN RCL 19 R/S RCL 22 R/S LBL DEG RC* 20 PGM 02 A RCL 21 PGM 02 B PGM 02 D RTN LBL SUM PGM 02 SBR DMS RTN LBL B 0 STO 00 STO 07 RCL 54 INT STO 08 2 STO 21 1 6 . 3 STO 23 LBL SIN SBR DEG PRT AD OP 20 SUM 07 DSZ 08 SIN RCL 07 ** RCL 00) STO 44 0 STO 00 STO 07 RCL 24 INT STO 08 3 2 . 9 STO 23 LBL ENG SBR DEG PRT AD OP 20 SUM 07 DSZ 08 ENG RCL 07 ** RCL 00) STO 19 0 STO 00 STO 07 RCL 25 INT STO 08 4 7 . 9 STO 23 LBL LOG SBR DEG PRT ADV OP 20 SUM 07 DSZ 08 LOG RCL 07 ** RCL 00) STO 22 RCL 44 RTN RCL 19 R/S RCL 22 R/S LBL C O STO 00 RCL 58 STO 08 LBL TAN SBR SUM XT . 2 GE RAD DSZ 08 TAN GTO Y^X LBL RAD OP 20 DSZ 08 TAN LBL Y^X RCL 00 RTN LBL D XT 1 EQ LNX 2 EQ 1/X 3 7 STO 00 RTN LBL

```
LNX . 8 7 STO 00 RTN LBL 1/X . 8 2 STO 00 RTN LBL E STO 07
. 1 5 STO 21 0 STO 20 SBR DEG * RCL 07 ) XT RCL 07 INV
GE PR XT RTN LBL PR RCL 07 RTN
```

5. Card 5

Labels Used:

A(001), SQRT(201), B(206)

Flags Used: None

Program:

```
LBL A STO 55 R/S ** ( 1 - RCL 42 ) ) - ( ( RCL 08 + RCL 16
+ RCL 17 + RCL 24 + RCL 25 + RCL 54 ) ** ( 1 - RCL 42 ) ) ) STO
53 RCL 24 + RCL 25 + RCL ** ( 1 - RCL 42 ) ) STO 08 *
. 4 ) STO 10 RCL 08 - RCL 10 ) ** 2 ) SUM 10 . 6 7 STO
09 ** 2 ) STO 04 6 0 STO 15 ** 2 ) STO 16 2 0 STO 00
7 5 STO o1 RCL 09 + RCL 04 + ( RCL 00 ** RCL 15 ) + (
RCL 00 ** RCL 16 )) STO 02 RCL 09 + RCL 04 + ( RCL 01
** RCL 15 ) + ( RCL 01 ** RCL 16 ) ) STO 03 RCL 53 *
. 4 ) SUM 55 RCL 53 * . 6 ) ** 2 ) SUM 55 RCL 18 **
RCL 02 ) 1/X * RCL 10 ) STO 05 RCL 55 XT RCL 05 GE SQRT RCL
55 RTN LBL SQRT RCL 05 RTN LBL B RCL 03 + RCL 57 ) RTN
```

ANNEX 3: DATA BASE

All 60 memory locations are used in the execution of the PARET model. Many of these storage locations are used repetitively during execution, and some form the permanent data base. The permanent data base forms the basis of many of the assumptions made in the model; changing these permanent variables causes direct changes in the output data.

Listed below are the contents of each data register. The number on the left corresponds to the register number. A (*) indicates that register is in the permanent data base, and therefore remains unchanged during program execution. When "computation" is listed in a register location, that register is used in arithmetic operations during execution and is not used for storage of any data to be used past the immediate routine accessing that register. In those cases where values other than computation are listed in the non-permanent data registers, those values form the intermediate data base, and are generally held in that location until the end of the execution of that module in which they are generated. By carefully restructuring the use of the memory locations, it would be possible to free up other memory locations to add to the permanent data base for future expansions of the program. Values listed sequentially are listed in the order in which they are generated within the model; the program listing provides

detailed information on the time that each of these locations is initially filled within each module.

register	contents
00	computation
01-06	used by random number routine
07	force ratio/number of recovery vehicles available/ m kills
08	time of battle/m organizational kills
09-13	used by random number routine
14	interdicted rate of advance/organizational %
15	time to reach battle site/direct support %
16	time to reach MCP/f organizational kills
17	time to rollup and recover/k organizational kills
18 (*)	time available for recovery
19 (*)	number of vehicles practical to recover
20-21	computation
22 (*)	number of recovery vehicles available
23	computation
24	computation/f direct support kills
25	probability of hit (recovery vehicle)/k direct support kills
26 (*)	blue survivors
27 (*)	red starting force
28 (*)	blue starting force
29 (*)	mean hookup time

register	contents
30 (*)	exchange ratio
31	computation
32 (*)	red breakpoint
33 (*)	% of combat vehicles which are unrecoverable
34-35 (*)	interdiction limits (e.g. 1 and 2 allow up to 50% interdiction)
36 (*)	recovery vehicle cross country speed
37 (*)	disorientation factor
38-39	computation
40-41 (*)	rollup and recovery limits (hours)
42 (*)	% self/like recovery
43 (*)	% line of sight factor
44	computation/f kills
45-46 (*)	probability of identification limits
47-49 (*)	%, m,f and k kills
50 (*)	inverse of recovery vehicle's priority as red target
51 (*)	time to recover the force
52 (*)	number of recovery vehicles killed during movement
53	computation
54	computation/m direct support kills
55	computation
56 (*)	exchange ratio factor
57 (*)	total clock time
58 (*)	total recovery vehicle losses
59	computation

APPENDIX B: GLOSSARY OF VARIABLES USED IN PARET

Variable Name	Description
B	HET DS turn around time
BO	initial blue force
BP	red force break point
BT	blue survivors
C	HET GS turn around time
D	recovery vehicle disorientation factor
Hmin	minimum HET requirement for DS evacuation
HMIN	minimum HET forecast
L	exchange ratio constant
L_s	probability of line of sight
MD	maximum number of trips to DS for HET's
NE	expected number of vehicles recovered
NR	number of recovery candidates
PK	probability of kill
QG	HET equivalents for GS
RI	interdicted rate of advance
RO	initial red force
RT	red survivors
S	blue suppressive fire factor
TB	time of battle
TC	critical time
TR	expected time to recover the force
TRR	time to rollup and restart for red force

Variable Name	Description
TE	time of exposure
X	exchange ratio
Z	reciprocal of target priority

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